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A METHODOLOGY FOR ESTIMATING THE ECONOMIC BENEFITS OF AN AIRCRAFT ENGINE WARRANTY

Martin P. Dooley, Captain, USAF
Richard E. Kells, Captain, USAF

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Aircraft engine warranties are used extensively in the commercial airlines industry. If the Department of Defense hopes to use warranties as a method of reducing engine life cycle costs, the costs and benefits of each warranty must be carefully analyzed. The methodology developed in this study provides framework to assist analysts in estimating the economic benefits of an engine warranty. A test application of the methodology details the benefits of a hypothetical DOD engine warranty, and includes a sensitivity analysis of the key variables. The study concludes that the basic method can be used to estimate the economic benefits of a wide range of engine and equipment warranties.

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A METHODOLOGY FOR ESTIMATING THE ECONOMIC BENEFITS OF AN AIRCRAFT ENGINE WARRANTY

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

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CHAPTER I

INTRODUCTION

Since the mid-1950s, the defense budget of the United States has declined more than fifty percent as a percentage of the total federal budget and as a percentage of the Gross National Product (GNP) (13:29-31). At the same time, inflation has diminished the real purchasing power of the funds available (6:9). These pressures make it imperative that persons responsible for spending defense dollars obtain the maximum value from each expenditure. One way Department of Defense (DOD) procurement personnel are attempting to cope with their decreased spending power is by looking beyond the initial purchase price of equipment and evaluating the "Life Cycle Cost" (LCC), which is the total cost of ownership over the expected life of the equipment, including the costs of purchase, logistic support, maintenance, and disposition (39:2).

One method of attempting to control life cycle cost is through the use of warranties. Warranties can be used to motivate a contractor by assigning him some of the financial responsibility for the operational reliability of his product. Some of the other management approaches to the control of life cycle cost include award fees,

support cost guarantees, design-to-cost incentives, and value engineering incentives (19:4-2 - 4-38). The technique promising the greatest reduction in life cycle cost while meeting other appropriateness criteria should be used in a given situation. This study will deal with the value of aircraft engine warranties.

The remainder of this chapter states the problem addressed in this research and provides background in the subjects of warranties and reliability. In addition, the justification, the objective, and the scope of this research are discussed.

Statement of the Problem

Selection of the most effective tool for managing life cycle cost requires that the future value of each possible approach be quantified. Studies have indicated that the use of warranties by the DOD may reduce logistics support costs and result in life cycle cost savings (22:162; 35:69). To properly evaluate a warranty proposal, the cost of the warranty should be weighed against the potential benefits. The problem was that no method was available for estimating the life cycle logistics support cost benefits of an aircraft engine warranty (10).

Warranty Theory

The Armed Services Procurement Regulation (ASPR) defines a warranty as, "a promise or affirmation given by

a seller to a purchaser regarding the nature, usefulness, or condition of the supplies . . . to be furnished [38:324-1]." It goes on to say:

> The principal purposes of a warranty in a Government contract are to delineate the rights and obligations of the contractor and the Government . . . and to foster quality performance [38:324-1].

A representative of a major U.S. airline stated that his company was seeking "total product support" from manufacturers through the use of warranties (16:1). In general, the purpose of a warranty is to hold the seller or manufacturer of a product responsible for the performance of that product in operational use (2:2-5; 31:1).

With most military aircraft equipment purchases, there is little direct incentive for a contractor to achieve reliability that exceeds the government's minimum acceptable standard. In fact, the contractor is motivated to meet the minimum and no more because design and production costs are very likely decreased and his opportunities to sell replacement parts, additional spares, and service contracts are increased, resulting in increased profit (3:2-2). Figure 1 shows the greater profit margin for the contractor when reliability is close to the minimum acceptable Mean Time Between Failures (MTBF) (20:24). With a warranty, however, the contractor is also responsible for the cost of logistic support to the extent specified in the warranty. In the latter case, increased reliability can lower his support costs, resulting in the

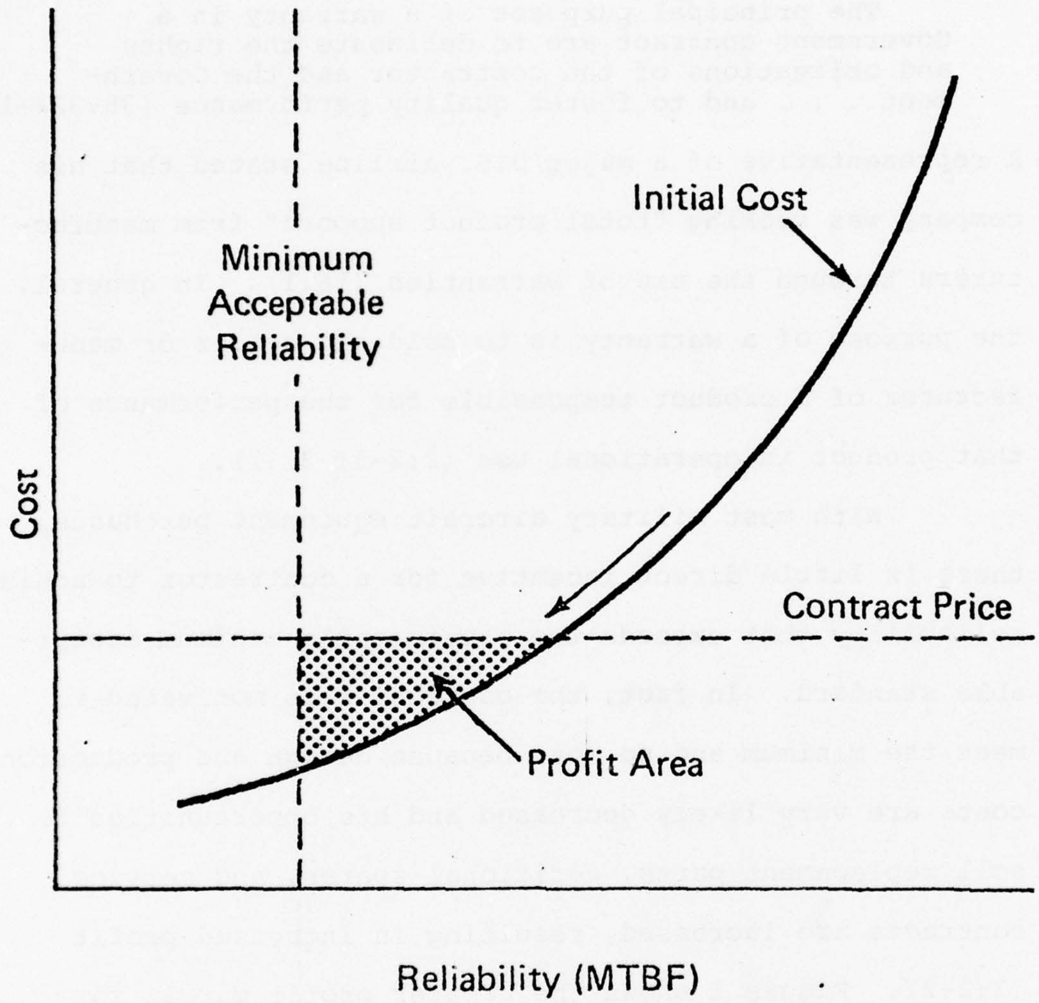

Figure 1. Manufacturer's Costs Without Warranty (20:Fig. 1)

situation shown in Figure 2 (20:27). The area of greater profit in the latter case is moved to the right at a higher MTBF (3:2-2), an area that benefits both the buyer and the seller. The assumption implicit in this analysis is that profit is the contractor's primary motivation, an assumption that may not be justified in the short run (13:240-243). While the graphs in Figures 1 and 2 only represent the theoretical relationships, they illustrate the financial incentive for a contractor to increase reliability when a warranty is in effect.

A properly structured and applied warranty can provide a contractor with a ". . . potential for substantial increase in overall contract profit [7:356]." Furthermore, ". . . the maintenance provisions will provide a steady workflow for the contractor for many years and may provide entry into similar depot maintenance work [7:356]."

If a warranty contract is properly applied and the incentives function according to the theory outlined above, a warranty can lead to higher equipment reliability (3:2-2). Greater reliability logically leads to increased equipment availability and lower support costs (15:12).

Another important benefit of a warranty is increased contractor awareness of maintainability characteristics. Defense equipment procurements typically contain stringent requirements for design features that

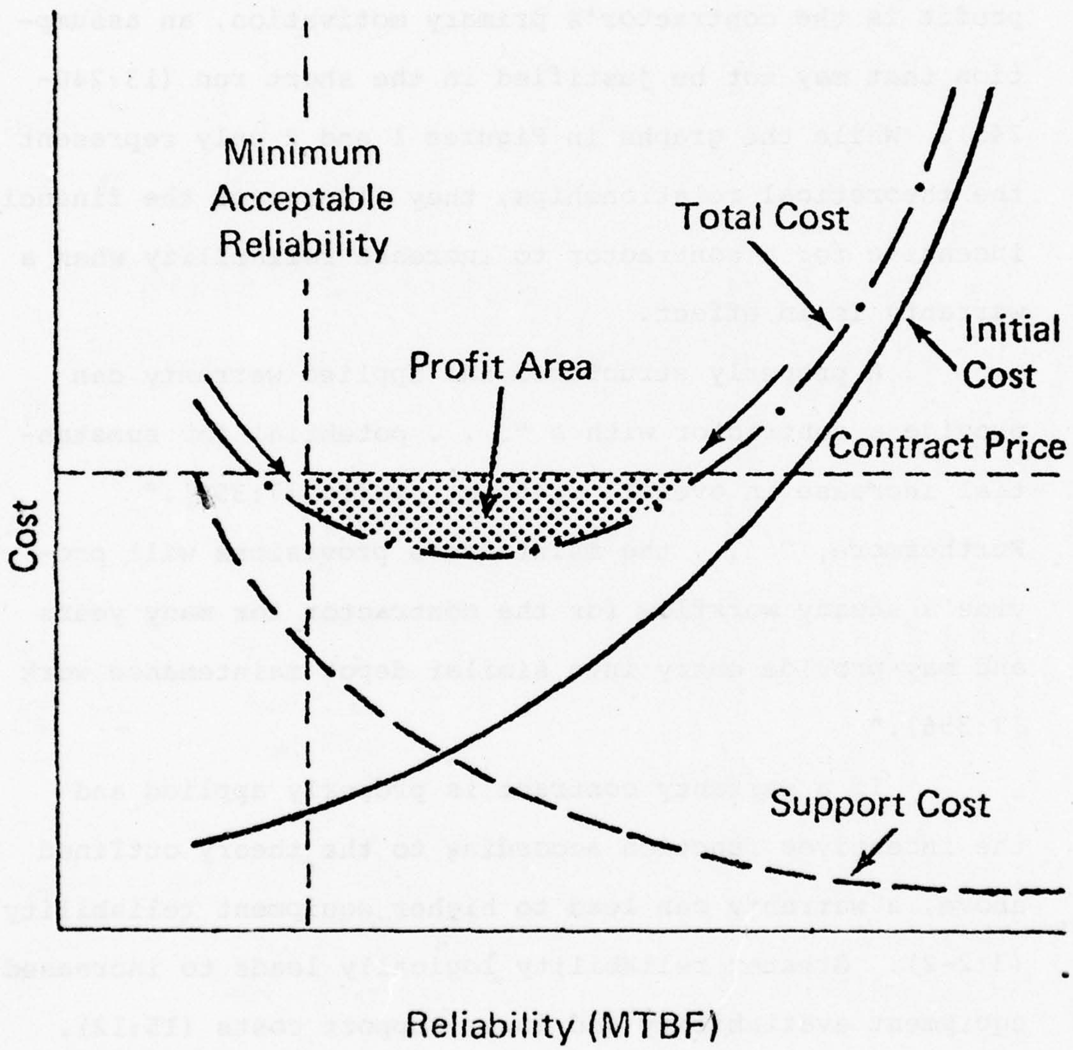

Figure 2. Manufacturer's Costs With Warranty (20:Fig 2)

facilitate troubleshooting and repair; however, these requirements sometimes make the equipment more difficult and more expensive to produce. If a warranty is in force, the contractor will have a vested interest in minimizing the labor and materials expended on maintenance because he will be responsible for a portion of the support costs.[1] Therefore, the contractor should be motivated to build in maintainability features and to develop efficient trouble-shooting and repair procedures.

The use of warranties is universal in the U.S. commercial airline industry and is growing in the DOD. Because of the high stakes involved in multi-million dollar aircraft equipment acquisitions, the warranties involved are carefully tailored to specific situations.

Numerous varieties of warranties are in use in the commercial aviation industry. The most widely used form is the Standard Warranty requiring that, for a specified calendar time, number of operating hours, or combination of both, the warrantor repair any failures or reimburse the customer for the costs of repairing the failures himself (4:13,17).

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[1]In this study, the contractor's portion of the support costs will be called "penalty payments." Penalty payments are reimbursements for the cost of labor and materials used to repair engine failures covered by the warranty when the repairs are performed by the user.

Aircraft Engine Warranties

The commercial airlines are leaders in the area of aircraft engine warranties. Extensive expansion of engine warranty provisions began with the introduction of the high-bypass turbofan engines used in the modern wide-bodied aircraft (16:13). The three major manufacturers of high-bypass engines and the engines they produce are General Electric (CF6), Pratt & Whitney (JT9), and Rolls-Royce (RB211). These companies have competitive warranty and product support packages included in the purchase price of each new engine (i.e., not separately priced) (16:17). The provisions of the General Electric CF6-50 warranty package exemplify the extensive coverage provided (14:3-1 - 9-1):

1. New Engine Warranty. New engines, thrust reversers, and modules are covered against failure for the initial 2,500 flight hours (takeoff to landing). Penalty payments are 100% to 2,000 hours, then prorated to 2,500 hours. Credit is given for parts, labor, and resultant damage. Refer to Appendix E for details of the CF6 New Engine Warranty.

2. New Parts Warranty. Penalty payments are 100% to 1,000 flight hours, then prorated for an extended time (from 2,000 to 12,000 hours depending on the part). Credit is given for parts and resultant damages only. The

warrantee can use the warranty that gives him the most benefit when the engine is still under the new engine warranty.

3. Ultimate Life Warranty. Key parts (turbine shafts, etc.) are covered on a prorated basis to 25,000 flight hours or 15,000 engine flight cycles (start, flight and shutdown), whichever comes first.

4. Campaign Change Warranty.[2] Covers time compliance actions required by GE or FAA such as modifications, inspections, etc.

5. Vendor Back Up Warranty. Vendor Warranties obtained by GE are passed on to CF6 users.

6. Vendor Interface Warranty. If environmental or interface problems arise with any control or accessory for which GE is responsible, GE will initiate corrective action and will provide warranty coverage in the event that the vendor fails to accept warranty responsibility.

Recent airline engine procurements have produced even more comprehensive warranty agreements including: (1) MTBF guarantees, (2) thrust deterioration guarantees, (3) fuel consumption rate guarantees, and (4) material cost (support costs per flying hour) guarantees (16:17).

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[2] A "campaign change" is a fleet-wide modification, inspection, or maintenance action similar to an Air Force Engineering Change Proposal (ECP) or Time Compliance Technical Order (TCTO) that applies to an entire fleet of aircraft or engines.

The use of warranties in the DOD is growing and there is considerable interest in applications on a larger scale. The applicability of warranties to equipment other than "black box" avionics packages is slowly developing. For example, the Navy's favorable experience with the Abex hydraulic pump on the F-14 has demonstrated that warranties have potential for non-electronic equipment procurements in the DOD (23:361).

Engine manufacturers have been reluctant to provide engine warranties to the Air Force. They consider the risks too great in view of the military aircraft operational and maintenance environment. The only warranty provision that has been widely used by the Air Force is a Correction of Deficiencies (COD) clause which

> . . . provides that the contractor shall use any and all actions necessary to correct any condition or characteristic in the supplies or services which is not in compliance with the contract [35:65].

Since the COD clause is subject to the limitations of the contract and is not a true warranty agreement, it has been difficult to prove contractor deficiencies (35:65).

Within the Air Force, an informal warranty was in effect between the Air Logistic Centers (ALCs) which provide depot repair of engines and the maintenance organizations they serve. Engines were warranted against failure for the first 100 operating hours after overhaul.

"The only exclusions to the Warranty . . . are foreign object damage, damage due to field personnel caused failures, and damage to the engine because of aircraft structural failures [35:167]."

A 1972 Logistics Management Institute (LMI) report made extensive comparisons between military and commercial practices in aircraft engine acquisition and maintenance (22). Among the conclusions resulting from the LMI analysis are the following:

- A warrantee almost always reduces life cycle support costs by reason of the warranty.

- A warrantee will benefit more by increases in reliability than from reimbursement for poor performance [22:162-3].

More recently, the DOD Procurement Management Review (PMR) of turbine engine acquisition and support studied the applicability of commercial-type warranties to military procurements. The PMR indicated that if the Air Force were to employ engine warranties, the following would probably be among the results:

- Higher initial prices for engines and engine spare parts.

- Better engine support during the initial system introduction (warranty period).

- Improved data base for spare parts forecasting.

- Less control over early engine modifications or changes.

- Reduced engine maintenance cost during initial system introduction (warranty period).

- Restrictions on engine operating and maintenance procedures which, if violated, could nullify any or all warranty claims.

- No certainty that reliability and durability performance will be improved [35:69].

Hypothetical Engine Warranty

Because an engine warranty is not currently in effect between an engine manufacturer and a DOD agency, a hypothetical engine warranty was designed to serve as a basis for the methodology developed in this study. The hypothesized warranty resembles the commercial new engine warranty and contains the following features:

1. A new engine, whether installed on a new aircraft or purchased separately as a spare, is warranted against failure for 500 flight hours or one year from the date of delivery, whichever occurs first.

2. Maintenance will be performed at Air Force installations by Air Force depot and base level maintenace personnel.

3. The engine manufacturer (warrantor) will reimburse the Air Force (warrantee) for the cost of parts required to repair failures covered by the warranty.

4. The engine manufacturer will reimburse the Air Force for the cost of labor required to repair failures covered by the warranty.

5. The following costs are excluded from reimbursement by the engine manufacturer:

a. Engine removal and replacement.

b. Engine storage, packaging and shipping.

c. Failures caused by foreign object damage (FOD).

d. Failures induced by damage caused by Air Force personnel.

e. Labor and expendable materials used in engine teardown and buildup during scheduled inspections.

The provisions of this hypothetical warranty were patterned after the warranty coverage of the General Electric CF6 engine (14:3-1 - 3-3). Appendix E contains the portion of The CF6 Engine Warranty that covers the new engine and thrust reversers.

The potential life cycle support cost benefits of the hypothetical engine warranty were grouped into two broad categories: (1) penalty payments, and (2) reliability improvement benefits. The penalty payments directly offset support costs by reimbursement from the warrantor. The reliability improvement benefits are savings realized as a result of increased reliability motivated by the warranty. Both categories of warranty benefits and the manner in which they will be estimated are discussed in greater detail in Chapter II.

Reliability

Another concept essential to this research is reliability. Reliability is defined as "the probability

that a system, subsystem, or equipment will perform a required function under stated conditions without failure for a specified period of time [34:1-2]." The key elements of the definition are "probability," "stated conditions," "failure," and "time," which are discussed below.

Equipment failure is "considered to be a probabilistic event with some known distribution [5:16]." Newly introduced aircraft engines are generally subject to a "burn-in" period during which high, but rapidly decreasing failure rates are experienced. This period of "infant mortality" is a result of poor quality control, imperfections in the manufacturing process, and weaknesses in the equipment's design. As these shortcomings are corrected and the burn-in period passes, a steady failure rate is experienced over most of the remainder of the engine's life. Toward the end of the engine's life cycle, increasing failure rates result from fatigue and wearout of parts (1:608; 22:132; 8:21). The classic "bathtub curve" illustrating the three phases of an engine's life cycle is shown in Figure 3.

In this research, engine "failure" was considered a malfunction requiring time and/or material expenditures by base or depot maintenance personnel for correction. Organizational (flight line) maintenance such as preflight and postflight inspections, and routine servicing and adjustments were excluded.

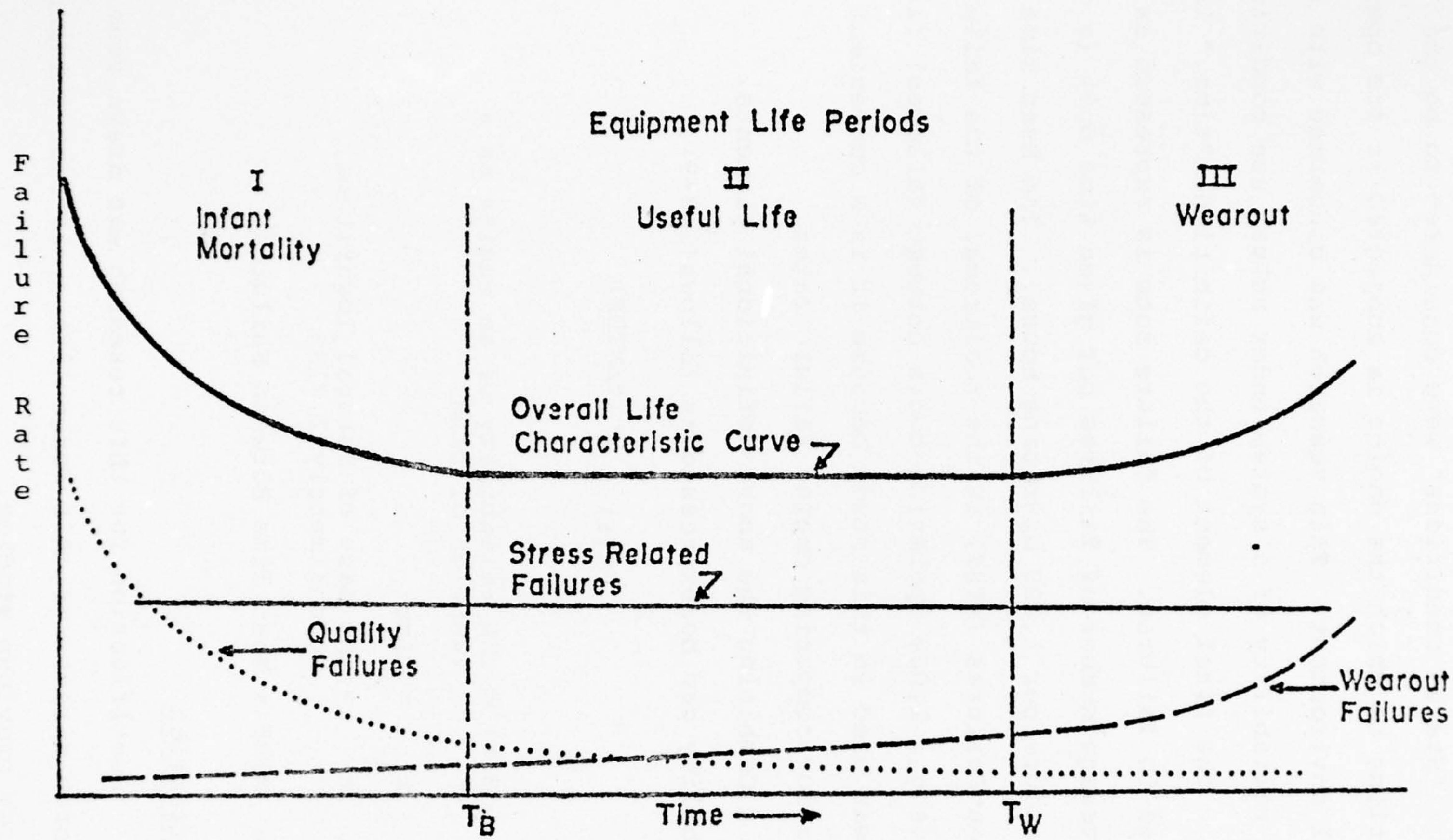

Figure 3. Bathtub Curve (1:Fig. 2-1)

"Stated conditions" were considered to be the conditions to which the engine is subjected in its operational environment. This research was concerned with the field reliability of a system under actual use conditions.

The final element of the definition, "time," is related to failures. The failure rate is expressed as the average number of failures per given time unit (e.g., one failure per 1,000 operating hours). The Mean Time Between Failures (MTBF) is the reciprocal of the failure rate (e.g., 1,000 operating hours between failures) (1:9). MTBF was used in this study because it is a convenient figure for comparing engine failure rates.

Combining the above definitional elements, reliability can be expressed as follows(1:8-9):

$$R(t) = e^{-(t/MTBF)}$$

where

$R(t)$ = the reliability of an engine as a function of time

t = time

e = the base of natural logarithms, approximately 2.7183

MTBF = Mean Time Between Failures.

Justification

Justification for this research was drawn from Air Force directives, Air Force life cycle cost guidance, and from previous studies.

Air Force Manual 1-1 (Draft) states: "The logistics system should operate at the lowest possible cost, consistent with maintaining a given level of operational effectiveness [36:51]." Moreover, AFM 400-1 goes on to say that, "Equipment should be designed to minimize the cost and effort required to support it, including acquisition, operating, and maintenance costs [29:5]." Consideration of life cycle cost early in a weapon system's development and the use of life cycle cost procurement techniques can often reduce downstream operations and support costs. According to the Life Cycle Cost Analysis Guide (18:C-14):

> There is considerable evidence in the LCC literature indicating that more money spent to improve the reliability of present equipments could have resulted in far greater reductions in operating and support costs. The task of getting increased funding for reliability improvement work during the development cycle would be easier if development managers more clearly understood the relationship between equipment reliability and cost.

The methodology developed in this research was intended to quantify and clarify some of the relationships between reliability and cost as they relate to the use of warranties as a procurement technique.

Individuals and agencies involved in the development and acquisition of Air Force weapon systems are specifically directed to ". . . determine and consider life cycle cost in various decisions associated with the development, acquisition and modification of defense systems and subsystems . . . [32:1]." As a result,

analyses are performed at various stages throughout the weapon system acquisition process to identify the various life cycle cost procurement approach alternatives and to select the most appropriate and effective alternative (18:4-10 - 4-30). The methodology presented in this study is an approach to analyzing one of the possible procurement techniques.

Specific justification for this research was derived from the recommendations of two studies of DOD practices in the acquisition and support of aircraft engines. A 1972 Logistics Management Institute (LMI) report recommended ". . . continued research and analysis into the specific application of warranties to military aircraft engines . . . [22:166]." In addition, a 1976 Procurement Management Review indicated that if the Air Force is to consider the use of engine warranties, it must have a means of evaluating the contractor's warranty price (35:73). The models in Chapter II establish a framework for estimating warranty benefits, thereby providing a basis for evaluating the price of a proposed warranty.

Research Objective

The objective of this research was to develop a methodology for estimating the life cycle logistics support cost benefits of an aircraft engine warranty. The warranty penalty payments and the cost avoidances

resulting from increased reliability are the logistics support cost benefits evaluated in this study.

Research Question

How can warranty theory and life cycle costing be used to estimate aircraft engine warranty benefits?

Scope

Warranties of the type common in the commercial airline industry have not been applied to military aircraft engine acquisitions and it is recognized that there are obstacles to DOD engine warranty procurement (22:163-66). However, this research was limited to an examination of the potential economic benefits of engine warranties, and no attempt was made to evaluate the feasibility of such warranties in the existing DOD procurement, operational, or maintenance environment.

The methodology developed in this study was designed to provide a general framework for warranty benefit analysis. To this end, the models within the methodology are simplified examples of the types of models that should be used when applying the methodology.

Formal validation of the methodology was not attempted. However, the methodology was applied using hypothetical data to assure logical validity and internal consistency, and to examine the relationships among key variables (12:120).

Overview

In the following chapters, the concepts that have been discussed in this chapter are further developed and applied. Chapter II contains the development of the methodology and descriptions of the individual models that contribute to the methodology. The assumptions and limitations that apply to the methodology conclude the chapter. Chapter III describes a test application of the methodology using hypothetical input data. The sensitivity analysis that was performed on key variables is also discussed in Chapter III. Finally, Chapter IV presents the conclusions from this study and recommendations for future research.

CHAPTER II

METHODOLOGY

As stated in Chapter I, the objective of this study was to develop a methodology for estimating the life cycle logistics support cost benefits of an engine warranty. The methods and models that were developed to meet this objective are presented in this chapter. First, the basic framework of the methodology is described. Then, the individual components and their associated models are explained. Finally, the data collection procedures are discussed, and the assumptions and limitations are summarized.

General Concepts

Engine warranties produce two economic benefits to the warrantee: (1) the penalty payments that are paid by the warrantor to offset repair costs of failed engines covered by the warranty, and (2) logistics support costs that are avoided by reliability improvements that are attributable to the warranty (22:161). The total warranty benefit is the combination of these two variables:

$$B = P + R$$

where

B = total warranty benefit

P = penalty payments

R = reliability improvement benefits

The methodology presented in this chapter is one approach to estimating B by computing the expected values of P and R.

The key variable or unknown in estimating the penalty payments (P) and the reliability benefits (R) is the reliability level achieved by the warranty. In this study, Mean Time Between Failure (MTBF) is used as the measure of reliability, and the warranty achieved reliability variable is $MTBF_a$. A primary concept or underlying assumption of this methodology is that warranty theory (see Chapter I) can be applied to estimate $MTBF_a$. More specifically, the methodology assumes that the manufacturer (warrantor) will strive to achieve his minimum total cost associated with the warranty (see Figure 2). In addition, the methodology assumes that the manufacturer accomplishes the reliability growth by testing and making improvements prior to the first delivery (fleet introduction). Once $MTBF_a$ is estimated, life cycle costing techniques are applied to compute the expected values of the penalty payments (P) and the reliability benefits (R).

The present values of the warranty benefits are computed in the methodology to account for the time value of money. The present value of an expected future benefit is the amount that would have to be invested now, at some

compound interest rate (discount rate), to yield the benefit amount by the time of the expected benefit. The Department of Defense normally uses a 10% discount rate (40:14-15).

To simplify the models used in the methodology, a constant failure rate (1/MTBF) is assumed for each year. Because engine failure rate distributions may vary with the type of engine and the production group (22:52), the MTBF values used in the methodology may have to be adjusted for succeeding years after delivery. If the failure rate is expected to be constant over the life of the engine, these adjustments are not required.[3]

The major underlying assumptions of this methodology are summarized below:

1. Warranty theory can be used to estimate achieved reliability ($MTBF_a$).

2. Reliability growth is accomplished prior to fleet introduction.

3. Life cycle costing methods are applicable when estimating penalty payments (P) and reliability benefits (R).

4. The engine failure rates are constant during each year.

<u>Note</u>: The models developed for use in this

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[3]For example, analysis of 15 quarters of unscheduled removal data on the TF33-P-7 engine from 1974 through early 1977 indicates a relatively constant failure rate of .0005428 failure per hour per engine (MTBF = 1842 hrs).

methodology are highly simplified. They were designed to be understandable examples of the types of models that must be used when applying the methodology. Users should modify or supplant these models to satisfy individual user requirements.

Achieved Reliability

According to warranty theory, the manufacturer (warrantor) will attempt to achieve a reliability level ($MTBF_a$) that will minimize the total costs associated with the warranty (see Figure 2). The manufacturer's warranty related costs fall into two categories: penalty payments and the costs of reliability growth. The penalty payments can be estimated using a logistics support cost model that includes only the costs for which the warrantor would be held responsible. The model can be exercised for several MTBFs over the probable range of reliability. When sufficient data points have been generated, any of several curve fitting techniques may be used to determine a penalty payment function.

The cost to achieve a given MTBF can be estimated using a reliability growth model and assigning costs to the testing and development associated with reliability improvement efforts. Again, by making estimates of the cost to achieve various levels of reliability, curve fitting can be used to determine a function for the cost of reliability growth.

The penalty payment function and the reliability growth cost function can then be combined to yield a total cost function. The minimum point of the total cost function can be approximated mathematically, graphically, or iteratively. These three approaches are outlined below.

First, the equations of the penalty payments function and the reliability growth cost function can be added algebraically. Their sum is the total cost function, and the minimum point of the total cost function can be found using the classical minimization procedures of calculus. Second, the values of penalty payments and the corresponding reliability growth cost for selected MTBFs can be added. These sums of costs for the selected MTBFs can be plotted graphically and the minimum point of the total cost curve can be approximated by observation. Third, the numeric sums of penalty payments and reliability growth cost for various levels of MTBF can be compared to determine the approximate minimum. Then, the penalty payments and reliability growth cost can be computed for MTBFs at narrower intervals near the approximate minimum determined earlier. Again, the sums can be compared to determine a more accurate approximate minimum, and so on.

In this study, the penalty payments were estimated using the penalty payment model described in the next section. Penalty payments were computed for each year, discounted to present value, and then summed to find the total present value of penalty payments for a given MTBF.

The cost of reliability growth was estimated using an adaptation of a model developed by the Logistics Management Institute (LMI). The basis of the model is the Duane Growth Model published in 1962 by J. T. Duane of General Electric Company (21:40). Duane found that, during a continuous reliability improvement program, when the cumulative failure rate was plotted against cumulative test hours on a log-log scale, the data points fell along a straight line. The slope of the failure rate line, alpha, indicates the rate at which the failure rate is improving, or, the reliability growth rate (8:459). Experience and research have indicated that alpha generally ranges from approximately .3 to .5 when a vigorous and systematic reliability improvement program is pursued (21:40; 8:460; 27:11). LMI assigned costs to various elements of the reliability growth process and expressed the variable costs as a function of the MTBF goal (21:41). The Duane Growth Model and the LMI model are described in greater detail in Appendix B.

Penalty Payment Model

Once the warranty achieved reliability ($MTBF_a$) has been estimated, the expected warranty penalty payments can be computed by applying life cycle costing methods within the framework of the warranty provisions. Under the provisions of the engine warranty considered in this study (see Chapter I), penalty payments fall into two

categories: labor and parts. Labor payments are based on negotiated allowance rates for base and depot level labor expenses incurred in the repair of failed engines under warranty. Parts payments are based on the current unit price of the part at the time of repair. To compute the expected penalty payments, labor and parts payments are estimated for each year the warranty is in effect, and these annual estimates are then summed to arrive at the expected total value. This process and the related formulas are described in the following paragraphs, and illustrated in Figure 4.

Assuming a constant failure rate for each year and new engine deliveries at the beginning of the year, the expected number of engine failures covered by the warranty for year i (WF_i) can be computed using the following formula:

$$WF_i = (FW)(DEL_i)(W/MTBF_{ai})$$

where

- FW = estimated fraction of failures covered by warranty
- DEL_i = delivered new engines under warranty for year i
- W = warranty period in operating hours
- $MTBF_{ai}$ = warranty achieved MTBF for year i

The number of base level repairs for year i (NBR_i) generated by the warranty failures (WF_i) can be computed using the formula:

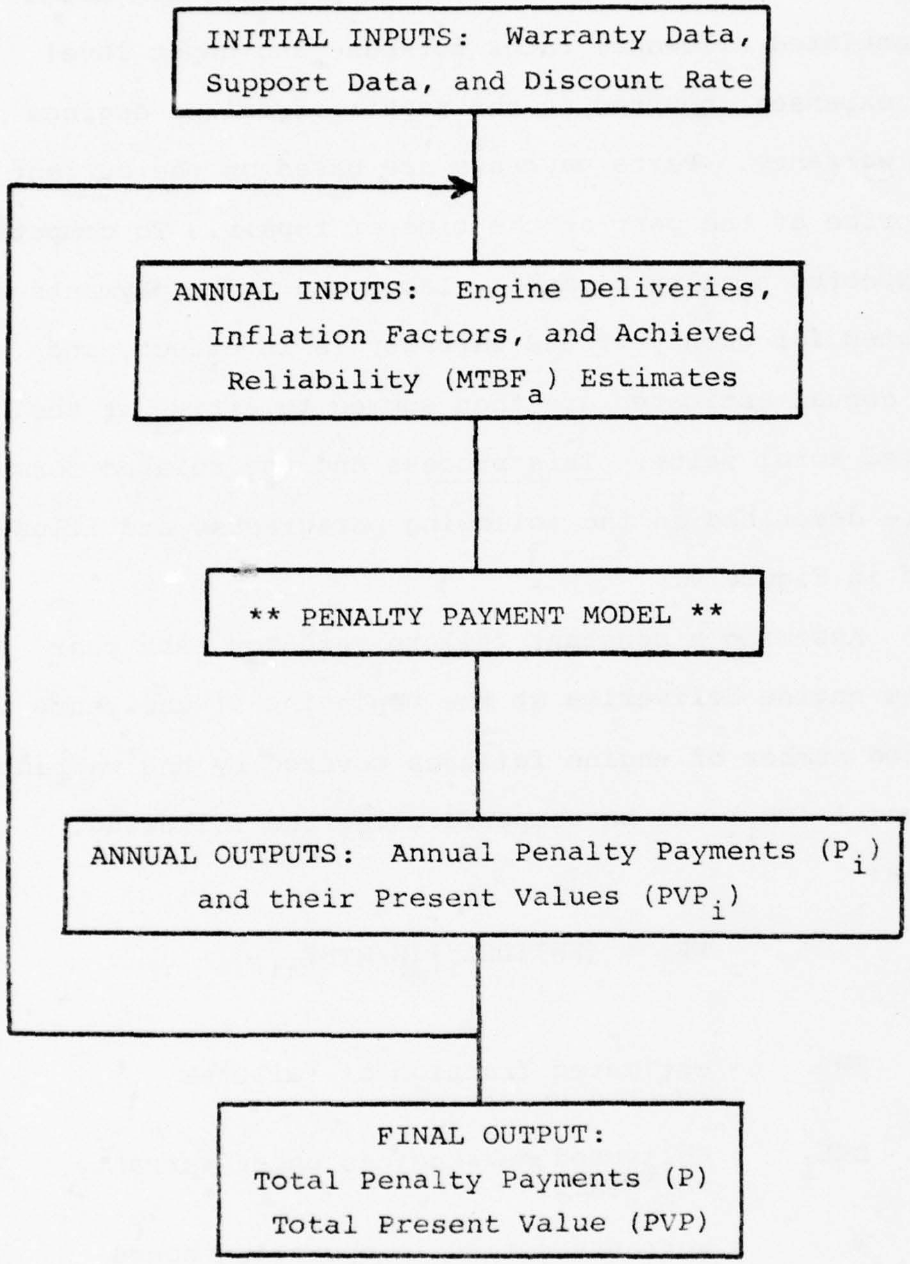

Figure 4. Penalty Payment Model

$$NBR_i = (ERTS)(WF_i)$$

where

ERTS = fraction of engines repaired at base level

The remaining failed engines under warranty are the number of depot repairs for year i (NDR_i):

$$NDR_i = WF_i - NBR_i$$

The estimated annual labor payment ($LABOR_i$) is the sum of base labor payments (BLP_i) and depot labor payments (DLP_i):

$$LABOR_i = BLP_i + DLP_i$$

where

BLP_i = $(NBR_i)(BMH)(BLA)$

DLP_i = $(NDR_i)(DMH)(DLA)$

NBR_i or NDR_i = number of base or depot repairs for year i

BMH or DMH = average manhours per repair at base or depot

BLA or DLA = warranty labor allowance rate at base or depot

The estimated annual parts payment ($PARTS_i$) is the sum of base parts payments (BPP_i) and depot parts payments (DPP_i) times an inflation factor (OMX_i)[4]:

$$PARTS_i = (BPP_i + DPP_i)(OMX_i)$$

---

[4]The inflation factor is only applied to parts because the labor rate is fixed by the warranty. The inflation factor (OMX_i) used in this study is a linear projection of the Department of Defense Operations and Maintenance inflation index (37:Atch 49).

where

$BPP_i = (NBR_i)(BPA)$

$DPP_i = (NDR_i)(DPA)$

NBR_i or NDR_i = number of base or depot repairs for year i

BPA or DPA = average parts allowance per repair at base or depot level

The estimated annual penalty payment (P_i) is the sum of the estimated labor and parts payments:

$$P_i = LABOR_i + PARTS_i$$

If a present value (PVP_i) is desired, the estimated annual penalty payment (P_i) is multiplied times a discount factor (DIS_i):

$$PVP_i = (P_i)(DIS_i)$$

where

$DIS_i = 1/(1+DR)^i$ = discount factor for year i

DR = discount rate

The total penalty payment (P) is the sum of the annual penalty payments (P_i):

$$P = \sum_{i=1}^{n} P_i$$

where

n = the number of years the warranty is in effect

The total present value (PVP) is the sum of the annual present values (PVP_i):

$$PVP = \sum_{i=1}^{n} PVP_i$$

Reliability Benefit Model

The reliability improvement attributable to a warranty is the difference between the expected reliability without warranty ($MTBF_o$) and the warranty achieved reliability ($MTBF_a$). The monetary benefit of this reliability improvement is equal to the difference in the engine's life cycle logistics support costs (LSC) at $MTBF_o$ and its LSC at $MTBF_a$. A life cycle cost model or logistics support cost model must be applied to compute these LSC values. The Air Force publication, Analysis of Available Life Cycle Cost Models and Their Applications (17), lists several models that can be used to analyze engine support costs at different levels of reliability. Selection of a model will depend on the needs of the user (cost detail, accuracy, etc.), and the availability of a model. The selected model must meet two basic requirements: (1) it must be sensitive to reliability changes, and (2) it must reflect life cycle logistics support costs (annual support costs inflated and summed over time). If the available models do not meet these requirements or do not completely fit the user's needs, the models can usually be modified to perform the required tasks. In addition, data collection can be greatly simplified by eliminating the parts of the selected model that are not sensitive to reliability changes (fuel costs, overhead, etc.).

The reliability benefit model developed for this study is based, in part, on the Air Force Logistics Command Logistics Support Cost (LSC) Model (25) and the Air Force Cost of Ownership Handbook (26). The developed model is designed to show how a modified LSC model can be utilized to estimate reliability improvement benefits. The model: (1) provides life cycle LSC benefit information, (2) is sensitive to MTBF changes, and (3) considers only those costs that change directly with MTBF. Three cost elements are considered: (1) base level repair of failed engines, (2) packing and shipping to depot of failed engines that cannot be repaired at base level, and (3) overhaul at depot of failed engines that cannot be repaired at base level. Other LSC cost elements, such as scheduled maintenance, maximum time overhaul, fuel, etc., are excluded from the model because of their lack of sensitivity to changes in MTBF. In addition, it is assumed that the ratio of procured spare engines to installed engines would not be changed because of expected warranty related reliability improvements.

To find the reliability benefit of a warranty, the logistics support cost with the warranty is subtracted from the logistics support cost without the warranty. The resulting value is the reliability benefit of a warranty. The reliability benefit model developed for this study is described in the following paragraphs, and illustrated in Figure 5.

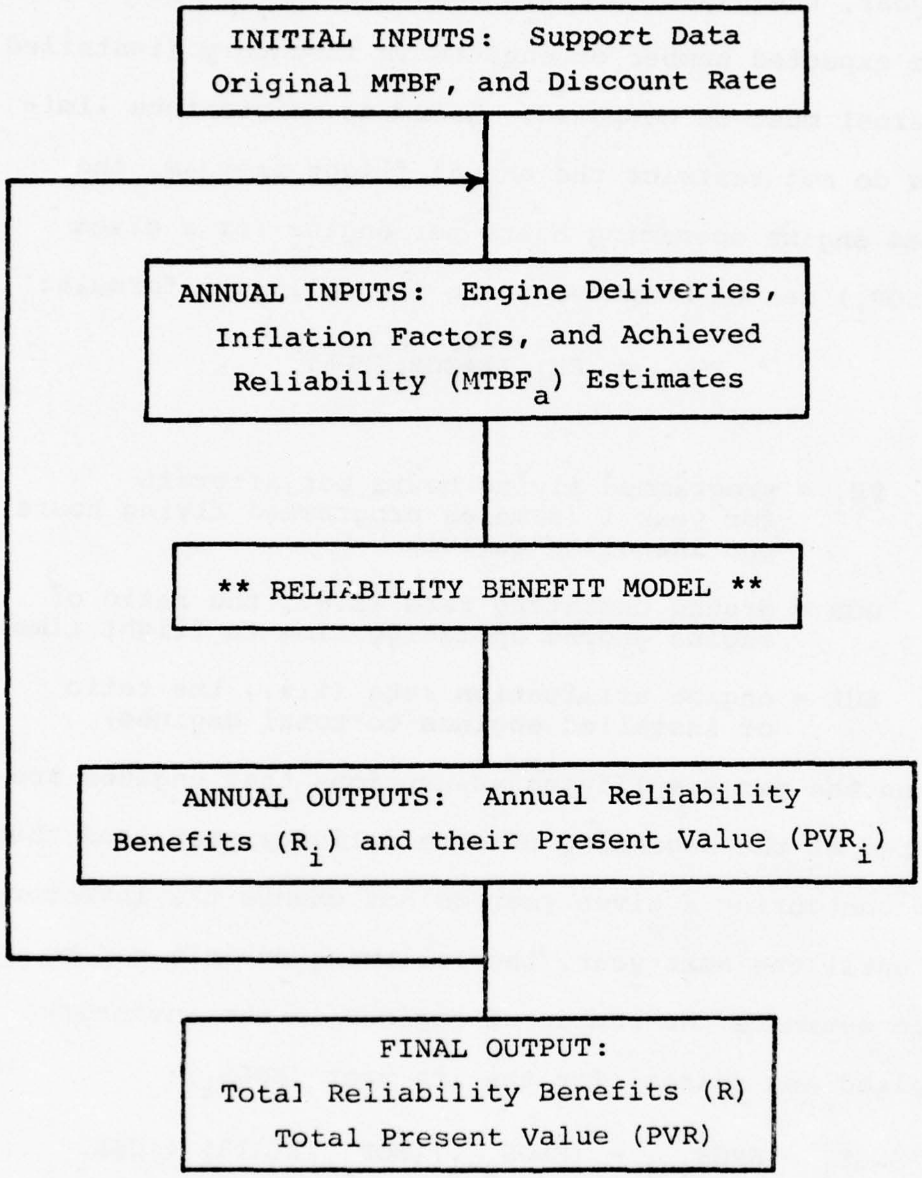

Figure 5. Reliability Benefit Model

To estimate the number of engine failures for a given year, the expected engine operating hours per engine and the expected number of engines in inventory (installed and spares) must be computed. Assuming maintenance limitations do not restrict the annual flight program, the expected engine operating hours per engine for a given year (EOP_i) can be computed using the following formula:

$$EOP_i = (FH_i)(1+GOR)(EUR)$$

where

FH_i = programmed flying hours per aircraft for year i (same as programmed flying hours per installed engine)

GOR = ground operating rate (i.e., the ratio of engine ground operating time to flight time)

EUR = engine utilization rate (i.e., the ratio of installed engines to total engines)

By using the two simplifying assumptions that engines are delivered at the beginning of each delivery year, and that attritions during a given year do not change the inventory level until the next year, the following formula can be used to estimate the number of engines in the inventory (installed and spares) for the ith year ($ENGS_i$):

$$ENGS_i = ENGS_{i-1} - (ENGS_{i-1})(EOP_{i-1})(ATR) + DEL_i$$

where

$ENGS_{i-1}$ = number of engines in previous year

EOP_{i-1} = operating hours per engine in previous year

ATR = attritions per engine operating hour

DEL_i = number of delivered new engines for year i

The results of the two previous formulas can be used to estimate the annual number of engine failures (EF_i). As with the penalty payment model, a constant failure rate for each year is assumed:

$$EF_i = (ENGS_i)(EOP_i/MTBF_i)$$

where

$ENGS_i$ = number of engines in inventory for year i

EOP_i = engine operating hours per engine for year i

$MTBF_i$ = expected mean time between failure (i.e., the inverse of the failure rate) for year i

The number of base level repairs (NBR_i) resulting from the engine failures can be estimated using the following formula:

$$NBR_i = (ERTS)(EF_i)$$

where

ERTS = fraction of engines repairable at base level

EF_i = number of engine failures during year i

The remaining failed engines are repaired at depot level:

$$NDR_i = EF_i - NBR_i$$

To estimate the cost of base level engine repairs for a given year, the expected material and labor costs are computed separately. The average cost of materials per repair at base level (CBM) can be estimated by the following formula:

$$CBM = (BMH)(BMR) + BRP$$

where

BMH = average manhours per repair at base level

BMR = base consumable materials rate (nuts, washers, rags, etc.)(expressed as a cost per manhour)

BRP = average cost of replacement parts per repair at base level

The estimated cost of base materials for year i (BM_i) is the number of base repairs (NBR_i) times CBM:

$$BM_i = (NBR_i)(CBM)$$

The average base labor costs per repair (CBL) can be estimated by the following formula:

$$CBL = BLR\ (RMH+BMH)$$

where

BLR = base labor rate (cost per manhour)

RMH = average manhours to remove and replace an engine

BMH = average manhours per repair at base level

The estimated cost of base labor for year i (BL_i) is the number of base repairs (NBR_i) times CBL:

$$BL_i = (NBR_i)(CBL)$$

If a failed engine cannot be repaired at base level, it must be shipped to the depot for overhaul. The cost of packaging and shipping failed engines to the depot for a given year (PSC_i) can be estimated using the following formula:

$$PSC_i = (NDR_i)(PSR)(EWT)$$

where

NDR_i = number of depot repairs for year i

PSR = packing and shipping rate (cost per pound)

EWT = engine and associated packaging weight

The average cost of an engine overhaul (COH) can be estimated using the following formula:

$$COH = (EOH)(EUC)$$

where

EOH = average cost of overhaul as a fraction of the engine unit cost

EUC = engine unit cost

The estimated depot, failure related, overhaul cost for a given year (DC_i) is the number of depot repairs (NDR_i) times COH:

$$DC_i = (NDR_i)(COH)$$

The expected logistics support cost for a given year (LSC_i) can now be computed using the following formula:

$$LSC_i = (BM_i+BL_i+PSC_i+DC_i)(OMX_i)$$

where

BM_i = base materials cost for year i

BL_i = base labor cost for year i

PSC_i = cost of packing and shipping for year i

DC_i = depot overhaul cost for year i

OMX_i = inflation factor for year i

By utilizing the LSC formulas described in the previous paragraphs, the logistics support costs with and without warranty can be estimated for a given year. By subtracting these two LSC values, an expected reliability benefit for year i (R_i) can be computed:

$$R_i = LSCO_i - LSCA_i$$

where

$LSCO_i$ = logistics support cost at $MTBF_o$ for year i

$LSCA_i$ = logistics support cost at $MTBF_a$ for year i

If a present value (PVR_i) is desired, the estimated annual reliability benefit (R_i) is multiplied times a discount factor (DIS_i):

$$PVR_i = (R_i)(DIS_i)$$

where

$DIS_i = 1/(1+DR)^i$ = discount factor for year i

DR = discount rate

The total reliability benefit (R) is the sum of the annual reliability benefits (R_i) over the expected life of the engine:

$$R = \sum_{i=1}^{n} R_i$$

where

n = engine's expected life in years

The total present value (PVR) is the sum of the annual present values (PVR_i):

$$PVR = \sum_{i=1}^{n} PVR_i$$

Total Benefit

As stated earlier in this chapter, engine warranties produce two economic benefits to the warrantee: (1) the penalty payments that are paid by the warrantor to offset repair costs of failed engines covered by the warranty, and (2) logistics support costs avoided by reliability improvements that are attributable to the warranty (22:161). These two benefits can be estimated by applying selected models of the type described in this chapter. Once the penalty payments and reliability benefits are estimated, the total expected warranty benefit over the life of the engine can be computed by combining the two benefit estimates:

$$B = P + R$$

where

B = total warranty benefit

P = penalty payments

R = reliability improvement benefits

The total present value of the warranty is the combination of the two benefit present values:

$$PVB = PVP + PVR$$

where

PVB = total present value

PVP = present value of penalty payments

PVR = present value of reliability benefits

The models and key variables used to estimate the total benefit of an engine warranty are illustrated in Figure 6.

Input Data

Application of the proposed methodology to an actual aircraft engine was not within the scope of this study. In fact, if the methodology is to be applied to an actual situation, the models within the methodology must first be modified or supplanted to meet user requirements. For these reasons, this section was designed to provide the user with information on potential data sources that are applicable to a wide range of related models.

Input data for the types of models used in this study can be obtained or estimated from three general sources: (1) the contractor, (2) Air Force experts, publications, and records, and (3) system program information. The Cost of Ownership Handbook (26:Appx D) provides a comprehensive listing of Air Force and contractor generated data sources. Also, most model user handbooks provide details on how to obtain input data. In addition, assistance in collecting data and making estimates can be

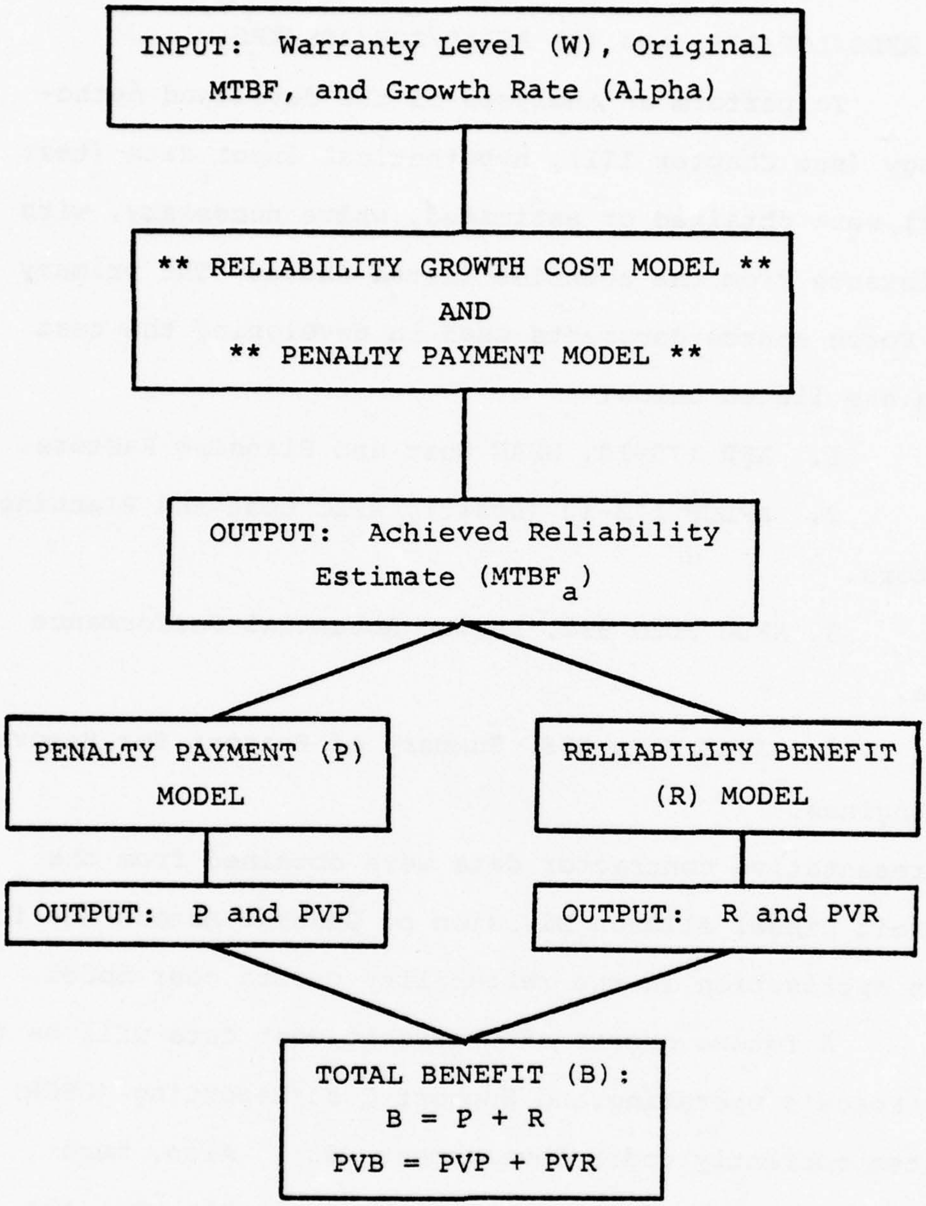

Figure 6. Total Benefit Model

obtained from the following agencies: (1) ASD/YZ, (2) AFLC/LOP/ACR, and (3) AFALD/AQE/AQS/XRS.

To perform an analysis of the developed methodology (see Chapter III), hypothetical input data (test data) were obtained or estimated, where necessary, with assistance from the agencies listed above. The primary Air Force source documents used in developing the test data are listed below:

1. AFR 173-10, USAF Cost and Planning Factors.

2. AFLCP 173-10 (Draft), AFLC Cost and Planning Factors.

3. AFLC Form 992, Engine Actuarial Performance Data.

4. AFLC Form 988, Summary of Reasons for Removal of Engines.

Representative contractor data were obtained from the Detroit Diesel Allison Division of General Motors (9) for test application in the reliability growth cost model.

A future source of ownership cost data will be the Air Force's Operating and Support Cost Reporting (OSCR) system currently under development (33). Also, more detailed engine information will be available when the new Comprehensive Engine Management System (CEMS) is fully implemented (30).

Summary of Assumptions

The following assumptions were employed in the methodology:

1. Warranty theory can be used to estimate achieved reliability ($MTBF_a$). Specifically, the manufacturer will attempt to achieve an MTBF that results in the minimum total cost associated with the warranty.

2. Reliability growth is accomplished prior to fleet introduction.

3. Life cycle costing methods are applicable in estimating warranty benefits.

4. The engine failure rates are constant during any given year.

5. The manufacturer's reliability improvement costs are captured by the LMI Cost of Reliability Growth Model.

6. The new engines are delivered at the beginning of each delivery year.

7. The engine logistics support cost elements used in the reliability benefit model capture the significant support costs that are sensitive to MTBF.

8. The ratio of procured spares to installed engines is not changed because of expected warranty related reliability improvements.

9. Maintenance limitations do not restrict the annual flight program.

10. Engine attritions during the ith year do not change inventory levels until the next year.

Assumptions four, six, and ten were used to simplify the models, and could be relaxed if more comprehensive models were employed.

Summary of Limitations

The methodology presented in this chapter is subject to the following limitations:

1. The models developed for use in the methodology are highly simplified. Users should modify of supplant these models to satisfy individual user requirements.

2. Since only hypothetical input data were used in the application of this methodology, the availability of usable input data was not completely assessed. The availability of input data should be considered when applying this methodology.

3. This methodology considers only the warranty benefits of penalty payments and reliability improvements. Less tangible benefits, such as improved manufacturer-user communications were not considered.

4. Validation of the methodology was limited to a test application to check the mathematics and internal consistency of the models.

CHAPTER III

ANALYSIS

This chapter addresses three questions concerning the methodology presented in Chapter II.

1. What are the results when the methodology is applied using hypothetical input data?

2. How does uncertainty in the reliability growth rate (alpha), and the warranty achieved reliability ($MTBF_a$) affect the estimated warranty benefits?

3. What impact does the choice of discount rate have on the present value of the warranty benefits?

To answer the first question, hypothetical input data (see Chapter II) were used in computerized versions of the models described in the methodology. The second and third questions were answered by varying the values of alpha, $MTBF_a$, and the discount rate over their possible ranges and observing the resultant changes in the estimated warranty benefits.

Test Application

The objectives of the test application were: (1) to check the mathematics and internal consistency of the methodology by exercising all its models and formulas;

(2) to present an example of how a user might apply the methodology to analyze a specific engine warranty; and (3) to help identify the key variables for sensitivity analysis.

The three primary models of the methodology are the LMI Cost of Reliability Growth model (21:35-42), the penalty payment model, and the reliability benefit model. To simplify the test application, these three models were converted to computer programs. The resulting Fortran programs and their outputs are listed in Appendix C. After the models were computerized, hypothetical input data were collected or estimated as described in Chapter II. System program data included an expected aircraft life of 15 years, and a total procurement of 750 engines delivered in the first five years of aircraft service. Refer to Appendix A for a detailed listing of the input data used in the test application.

The test application followed the pattern shown in Figure 6. The procedures and results are summarized below:

1. Based on an original MTBF of 400 hours, a warranty level of 500 hours, and an alpha of .4, the LMI Cost of Reliability Growth Model and the penalty payment model were applied to estimate the warrantor's minimum total cost. Figure 7 shows the resulting cost curves. The minimum total cost occurred at an MTBF of 425 hours ($MTBF_a$ = 425).

2. The penalty payment model and the reliability benefit model were applied using the expected $MTBF_a$ of 425 hours[5] and a discount rate of .10. The results are shown in Figures 8 and 9.

3. The total economic benefit of the warranty was estimated by combining the expected values of the penalty payments (P and PVP) and the reliability benefits (R and PVR). The resulting total warranty benefit was 86.257 million dollars with a present value of 47.445 million dollars.

Reliability Growth Sensitivity

The reliability growth rate (alpha) is the key variable in determining the cost of reliability growth (21:40). The literature indicates that alpha can normally range from .3 to .5 during a reliability improvement effort (8:460; 21:40). Variations in alpha change the slope of the reliability growth cost curve. Because the penalty payment curve is fixed by the terms of the warranty, changes in the slope of the reliability growth (RG) cost curve cause significant changes in the shape of the total cost (TC) curve. The first three graphs in Appendix D illustrate the impact of alpha on the total cost curve and its minimum cost point. At an alpha of .3 the minimum total cost is at the original MTBF ($MTBF_a = MTBF_o = 400$).

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[5]For the test application, it was assumed that the failure rate would be constant over the life of the engine.

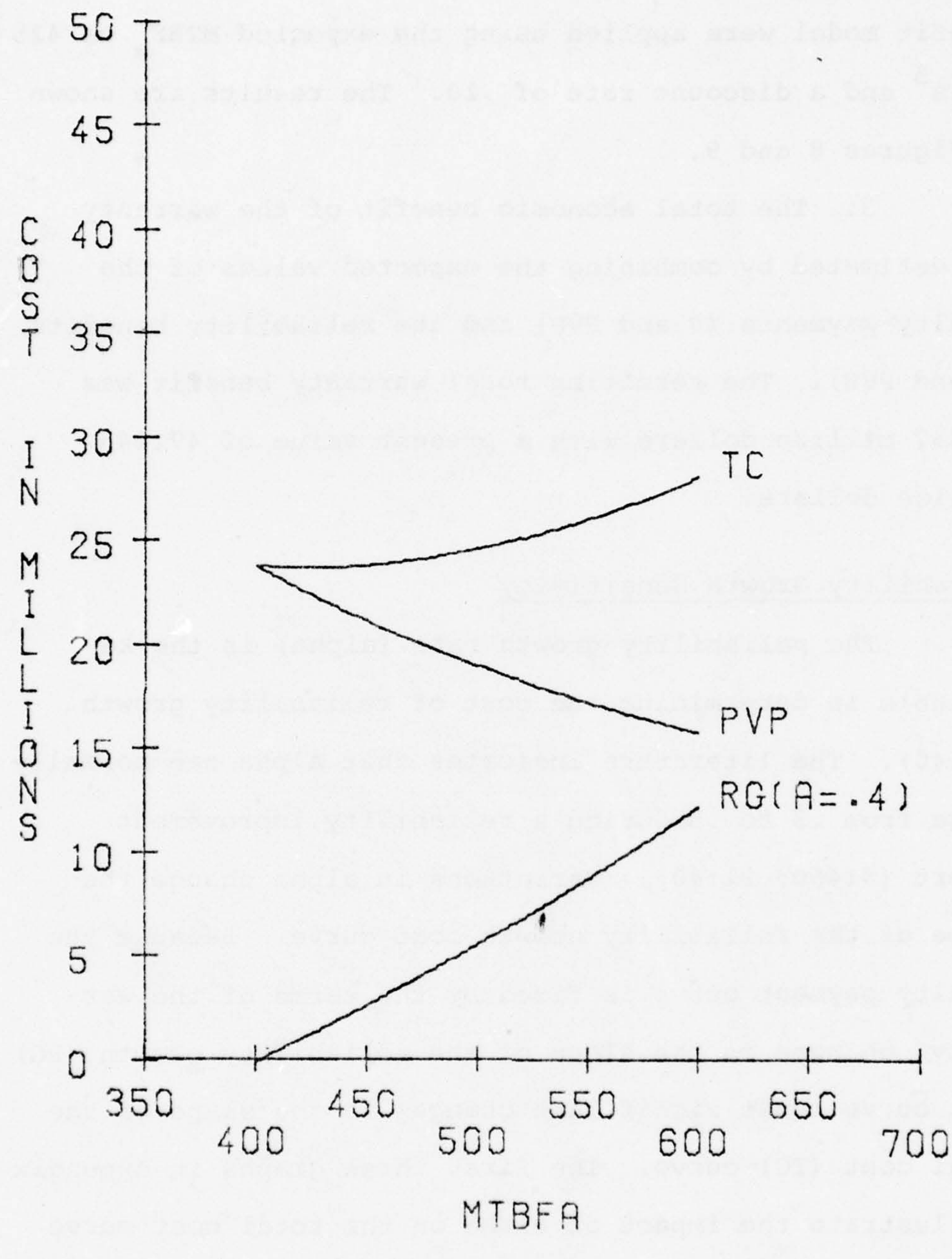

Figure 7. Manufacturer's Warranty Costs

PENALTY PAYMENT MODEL

```
    ENTER WARRANTY LEVEL(EG.=500.):
=500.
    ENTER WARRANTY ACHIEVED MTBF(EG.=750.):
=425.
    ENTER DISCOUNT RATE(EG.=.10):
=.10
```

ESTIMATED ANNUAL PENALTY PAYMENTS (IN MILLIONS):

YEAR	ENGS	LABOR	PARTS	PEN PAY	PV
1	100	0.706	2.965	3.671	3.337
2	200	1.413	6.242	7.655	6.326
3	200	1.413	6.510	7.923	5.953
4	150	1.060	5.071	6.131	4.187
5	100	0.706	3.515	4.221	2.621

TOTAL PENALTY PAYMENTS= 29.601 MILLION

TOTAL PRESENT VALUE= 22.425 MILLION

Figure 8. Penalty Payments

RELIABILITY BENEFIT MODEL

```
    ENTER ORIGINAL MTBF(EG.=350.):
=400.
    ENTER WARRANTY ACHIEVED MTBF(EG.=750.):
=425.
    ENTER DISCOUNT RATE(EG.=.10):
=.10
```

ESTIMATED ANNUAL RELIABILITY BENEFIT (IN MILLIONS):

YEAR	ENGS	LSCO	LSCA	BENEFIT	PV
1	100	7.651	7.201	0.450	0.409
2	299	24.083	22.666	1.417	1.171
3	496	41.667	39.216	2.451	1.841
4	641	55.928	52.638	3.290	2.247
5	735	66.674	62.752	3.922	2.435
6	728	68.611	64.575	4.036	2.278
7	721	70.603	66.450	4.153	2.131
8	714	72.646	68.373	4.273	1.994
9	707	74.279	69.910	4.369	1.853
10	700	76.017	71.545	4.472	1.724
11	693	77.705	73.134	4.571	1.602
12	686	79.394	74.723	4.670	1.488
13	679	80.983	76.219	4.764	1.380
14	673	82.645	77.783	4.861	1.280
15	667	84.265	79.308	4.957	1.187

TOTAL RELIABILITY BENEFIT= 56.656 MILLION

TOTAL PRESENT VALUE= 25.020 MILLION

Figure 9. Reliability Benefits

When the alpha is increased to .5, the minimum total cost is at approximately 475 hours ($MTBF_a$ = 475). In other words, the alpha range of .3 to .5 causes the reliability improvement estimate to vary from zero to 75 hours ($MTBF_a$ = 400 to 475).

Benefit Sensitivity

The warranty achieved reliability ($MTBF_a$) is the key variable in determining warranty benefits. The magnitude of $MTBF_a$ is a measure of how well the warranty has motivated the manufacturer to improve the reliability of the engine. The test application of the methodology resulted in an $MTBF_a$ estimate of 425 hours. However, the uncertainty in alpha gave a possible $MTBF_a$ range of 400 to 475 hours. To measure the impact of this $MTBF_a$ range on the warranty benefits (P and R), the penalty payment (P) model and reliability benefit (R) model programs were modified to perform sensitivity analysis (see Appendix C). The outputs from these sensitivity programs show the effects of uncertainty in $MTBF_a$ on the benefit variables (see Figures 10 and 11). Figure 12 shows the sensitivity of the total warranty benefits (B and PVB) to the possible range of $MTBF_a$. In addition, the sensitivity graphs in Appendix D illustrate the warranty benefits as a function of $MTBF_a$.

The benefit sensitivity results indicate that reliability benefit (R) is much more sensitive to variations

```
***P SENSITIVITY TO MTBFA***

    ENTER WARRANTY LEVEL(EG.=500.):
=500.
    ENTER DISCOUNT RATE(EG.=.10):
=.10
    ENTER LOWEST AND HIGHEST EXPECTED MTBFA TO THE
    NEAREST 5 HOURS(EG.=415.,655.):
=400.,475.


          PENALTY PAYMENTS (IN MILLIONS):

                MTBFA      P        PV
                 400.    31.451   23.826
                 405.    31.063   23.532
                 410.    30.684   23.245
                 415.    30.314   22.965
                 420.    29.953   22.692
                 425.    29.601   22.425
                 430.    29.257   22.164
                 435.    28.920   21.909
                 440.    28.592   21.660
                 445.    28.271   21.417
                 450.    27.956   21.179
                 455.    27.649   20.946
                 460.    27.349   20.718
                 465.    27.055   20.496
                 470.    26.767   20.278
                 475.    26.485   20.064
```

Figure 10. Sensitivity of Penalty Payments to $MTBF_a$

```
***R SENSITIVITY TO MTBFA***

    ENTER ORIGINAL MTBF(EG.=350.):
=400.
    ENTER DISCOUNT RATE(EG.=.10):
=.10
    ENTER LOWEST AND HIGHEST EXPECTED MTBFA TO THE
    NEAREST 5 HOURS(EG.=415.,655.):
=400.,475.
```

RELIABILITY BENEFIT (IN MILLIONS):

MTBFA	R	PV
400.	-0.000	-0.000
405.	11.891	5.251
410.	23.491	10.374
415.	34.813	15.374
420.	45.864	20.255
425.	56.656	25.020
430.	67.196	29.675
435.	77.495	34.223
440.	87.559	38.668
445.	97.397	43.013
450.	107.017	47.261
455.	116.425	51.416
460.	125.628	55.480
465.	134.634	59.457
470.	143.448	63.349
475.	152.076	67.160

Figure 11. Sensitivity of Reliability Benefits to $MTBF_a$

TOTAL BENEFIT SENSITIVITY TO MTBFA

BENEFIT VALUES (IN MILLIONS):

MTBFA	R	PVR	P	PVP	B	PVB
400.	0.	0.	31.451	23.826	31.451	23.826
405.	11.891	5.251	31.063	23.532	42.954	28.783
410.	23.491	10.374	30.684	23.245	54.175	33.619
415.	34.813	15.374	30.314	22.965	65.127	38.339
420.	45.864	20.255	29.953	22.692	75.817	42.947
425.	56.656	25.020	29.601	22.425	86.257	47.445
430.	67.196	29.675	29.257	22.164	96.453	51.839
435.	77.495	34.223	28.920	21.909	106.415	56.132
440.	87.559	38.668	28.592	21.660	116.151	60.328
445.	97.397	43.013	28.271	21.417	125.668	64.430
450.	107.017	47.261	27.956	21.179	134.973	68.440
455.	116.425	51.416	27.649	20.946	144.074	72.362
460.	125.628	55.480	27.349	20.718	152.977	76.198
465.	134.634	59.457	27.055	20.496	161.689	79.953
470.	143.448	63.349	26.767	20.278	170.215	83.627
475.	152.076	67.160	26.485	20.064	178.561	87.224

Figure 12. Sensitivity of Total Benefits to $MTBF_a$

in $MTBF_a$ than penalty payments (P). For example, a 10% increase in $MTBF_a$ (425 to 475) results in a 170% increase in R (57 to 152), but only a 10% decrease in P (30 to 26). Also, the same 10% increase in $MTBF_a$ results in a 130% increase in the total benefit (B) indicating the strong influence of the reliability benefit (R) on the total benefit (B). These relationships are shown in Figure 13.

Present Value Sensitivity

As discussed in Chapter II, the Department of Defense is normally required to use a discount rate of 10%. However, analysts can use other discount rates if they believe another rate would be more applicable (40:15). To examine the effect of various discount rates on the present values of the warranty benefits, computer programs were developed similar to those used to measure benefit sensitivity to $MTBF_a$ (see Appendix C). For this sensitivity analysis, $MTBF_a$ was held constant at 425 hours and the discount rate was varied from zero to 15%. Figure 14 shows the collective output from these sensitivity programs, and the resulting curves as shown in Figure 15.

The present value sensitivity results indicate that the present value of the reliability benefit (PVR) is much more sensitive to changes in the discount rate than the present value of the penalty payments (PVP). This

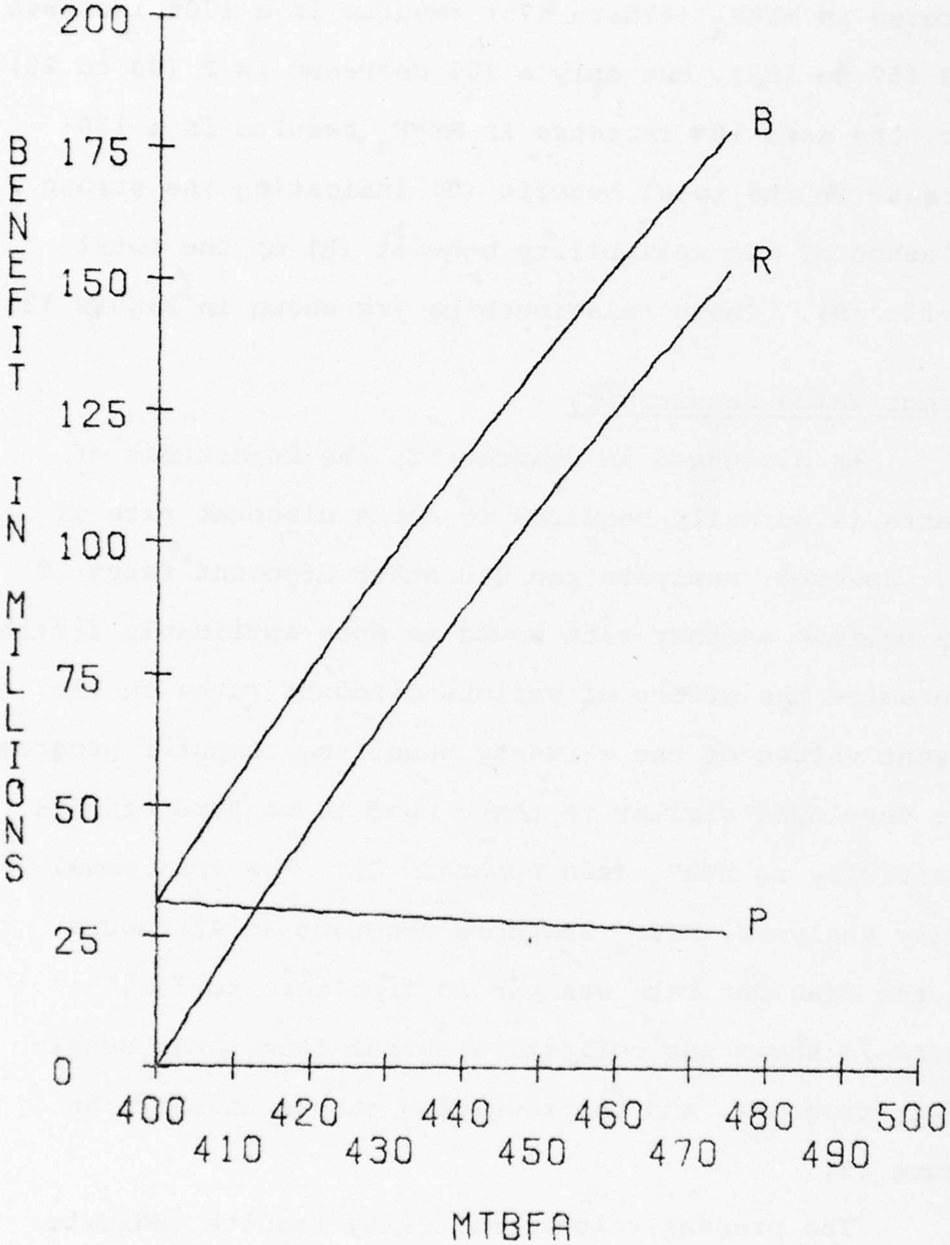

Figure 13. Benefit Sensitivity to $MTBF_a$

TOTAL BENEFIT SENSITIVITY TO DR

BENEFIT VALUES (IN MILLIONS):

DR	R	PVR	P	PVP	B	PVB
0.	56.656	56.656	29.601	29.601	86.257	86.257
0.01	56.656	51.698	29.601	28.737	86.257	80.435
0.02	56.656	47.283	29.601	27.910	86.257	75.193
0.03	56.656	43.345	29.601	27.119	86.257	70.464
0.04	56.656	39.823	29.601	26.361	86.257	66.184
0.05	56.656	36.667	29.601	25.635	86.257	62.302
0.06	56.656	33.832	29.601	24.939	86.257	58.771
0.07	56.656	31.281	29.601	24.271	86.257	55.552
0.08	56.656	28.931	29.601	23.631	86.257	52.612
0.09	56.656	26.902	29.601	23.016	86.257	49.918
0.10	56.656	25.020	29.601	22.425	86.257	47.445
0.11	56.656	23.313	29.601	21.857	86.257	45.170
0.12	56.656	21.751	29.601	21.311	86.257	43.072
0.13	56.656	20.348	29.601	20.786	86.257	41.134
0.14	56.656	19.059	29.601	20.280	86.257	39.339
0.15	56.656	17.881	29.601	19.794	86.257	37.675

Figure 14. Present Value Sensitivity to Discount Rate

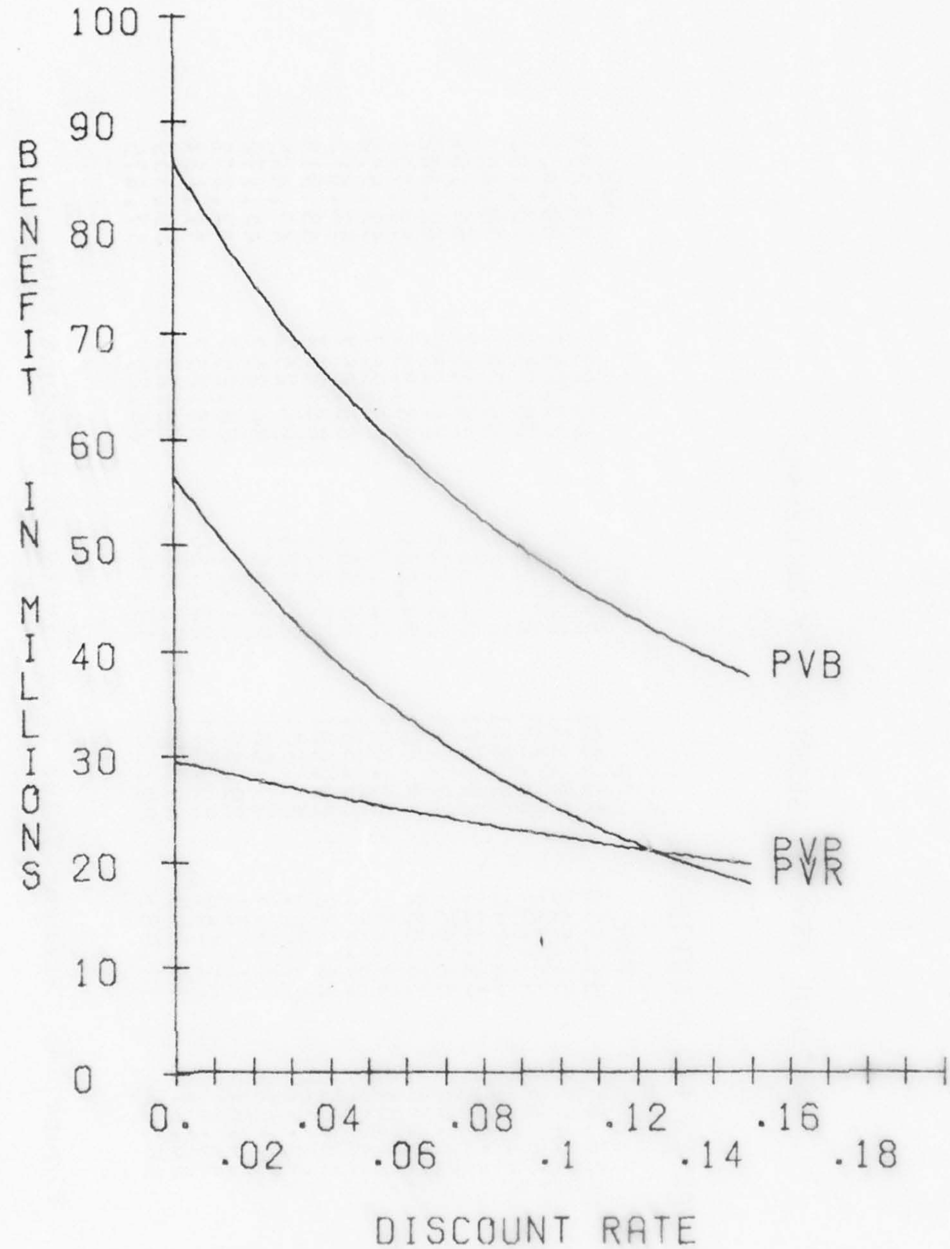

Figure 15. Present Value Sensitivity to Discount Rate

can be explained by the fact that penalty payments only occur during the first few years of the system's expected life because of the limited duration of the warranty. Consequently, penalty payments are less affected by discounting to present value because the total benefit of the penalty payments is realized in a shorter time interval.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

This study has used the concepts of warranty theory and life cycle costing to develop a methodology for estimating the life cycle logistics support cost benefits of an aircraft engine warranty. The contributing models were exercised in a test application and sensitivity analysis was performed on key variables in the models. This chapter presents the specific conclusions from the test application of the methodology, general conclusions from the overall research effort, and recommendations for future research.

Conclusions from the Test Application

As discussed in Chapter III, the test application of the methodology had three purposes. First, it exercised all of the models and equations contributing to the methodology, thereby acting as a check on the mathematics and model consistency. Second, the test application was an example of how a potential user might apply the methodology to evaluate the economics of an engine warranty in a given situation. Third, the test application helped to identify some of the key variables in the models and the

sensitivity of the warranty benefits to uncertainty in those variables.

The test application of the methodology led to five conclusions:

1. The methodology and the contributing models exhibit internal consistency. The equations and computer models developed for the methodology function as intended and provide the required estimates of the penalty payments and the reliability improvement benefits of an engine warranty.

2. The warranty may not provide a significant incentive for the manufacturer to improve reliability unless the reliability growth rate (alpha) is high. The input data used and the variables that were included in the models influenced the level of reliability achieved under the warranty; however, a substantial increase in penalty payments or a substantial decrease in the costs of reliability growth would be required to establish a clear incentive for reliability improvement.

3. Even relatively small reliability improvements before fleet introduction result in considerable savings in downstream logistics support cost, even when the savings are discounted to present value. This supports, in part, an analysis by the Logistics Management Institute (LMI) that indicated that upstream investment in engine reliability might be more economical in the long run than the current DOD practice of growing reliability after the

engines have been placed in operational service. The LMI study noted, however, that the analysis had not quantified the costs or effects of delaying production and fleet introduction while reliability was being improved (22:57-60).

4. The reliability improvement benefits (R) far outweigh the penalty payments (P). This finding also supports a conclusion of an LMI analysis of aircraft engine warranties (22:166).

5. The maximum price the Air Force should pay for a warranty is the present value of the total benefit when penalty payments and the reliability improvement benefits are the only factors considered. The logical negotiating range for the price of a warranty would be from the manufacturer's minimum total cost (plus a profit) to the present value of the expected total benefit. Other costs (such as warranty administration) and other benefits (such as reduced spare parts inventories) would certainly influence the final decision on the price of the warranty.

General Conclusions

In addition to the specific conclusions from the test application of the methodology, the overall research effort led to three general conclusions:

1. In response to the research question posed in Chapter I, it is concluded that warranty theory and life cycle costing can be used to estimate the life cycle

logistics support cost benefits of an aircraft engine warranty by applying the methodology described in this study.

2. The overall methodology is sound, but the models that contribute to it should be modified or replaced to satisfy the requirements of a specific analysis. The models used in the test application are simplified examples and were not intended to capture all of the possible variables that might apply in a given situation. In addition, the test application should be treated only as an example of how the methodology could be applied. Although an attempt was made to obtain "representative" input data, the data do not accurately reflect any real situation. Therefore, the outcome of the test application, as with any analysis, was largely a function of the data used. However, the conclusions concerning relationships among the variables and the relative magnitude of the impact of key variables on the outcome are considered valid.

3. The research objective was met. A methodology was developed for estimating the economic benefits of an aircraft engine warranty. Furthermore, the general methods used to approach the problem can be generalized beyond the analysis of aircraft engine warranties. The methodology should be applicable to the economic analysis of any warranty using the following general procedures:

a. Estimate the manufacturer's (warrantor's) total cost function based on his estimated reliability growth cost and his expected warranty costs.

b. Use the reliability level corresponding to the warrantor's minimum total cost as an estimate of the reliability that would be achieved under the warranty.

c. Apply an appropriate life cycle cost or logistics support cost model to estimate the warranty penalty payments or the value of the repairs and services required of the warrantor.

d. Apply an appropriate life cycle cost or logistics support cost model to evaluate the difference between the costs of logistics support at the expected reliability levels with and without the warranty.

e. Combine the two benefits estimated in steps c and d above to approximate the total economic benefit of the warranty.

f. Use experience and managerial judgment to evaluate any subjective factors or variables not captured by the models. Then, use the information provided by the analysis as an aid in the decision making process.

Recommendations for Future Research

Six potentially rewarding topic areas are recommended for future research:

1. Refinement and validation of the methodology developed in this study should be attempted using data from commercial airline warranty experience. Some of the simplifying assumptions (such as the failure rate distribution, the delivery schedule, and the attrition schedule) could be relaxed if more sophisticated models and computer programs were used. In the past, it has been difficult to obtain warranty data from airlines or engine manufacturers because both considered the information proprietary (22:161-2; 35:68). In the absence of airline data, validation of the basic methodology might be attempted using data from Air Force experience with warranties covering aircraft subsystems other than engines.

2. Further study is needed to validate a model for estimating the cost of reliability growth. A possible starting point is the LMI model used in this study (21: 35-42).

3. An analysis of the relative cost of developing engine reliability before fleet introduction versus growing reliability while the engine is in operational service is also recommended. As mentioned earlier, study in this area would entail quantification of the costs of delaying the start of production.

4. There should be an examination of the feasibility of the use of aircraft engine warranties

within the DOD. Many obstacles to engine warranties exist in the DOD and studies in the past have recommended against the use of warranties in aircraft engine procurements (22:166; 35:73). However, in view of increasing DOD use of off-the-shelf commercial aircraft and engines, specific engines and missions, or specific engine parts might be found suitable for the application of commercial type warranties in the future. In addition, the study might address ways of removing some of the impediments to warranties in the DOD and ways of limiting the warrantor's risk to a level acceptable to an engine manufacturer.

5. Additional study of commercial airline experience with warranties on aircraft engines and other equipment would be beneficial. In particular, the lessons learned by the airlines could help military procurement planners avoid potential problems. Also, recognizing that the airlines and the DOD operate in different environments, the study could include analysis of the applicability of airline warranty experience to the DOD.

6. Because of the high level of interest in incentive contracting, a study of the amount of incentive provided by each of various incentive contracting techniques would also be of value. The study could include such procurement techniques as award fees, design-to-cost incentives, value engineering incentives, warranties, and others.

APPENDIX A

VARIABLE LIST

This appendix is a summary of the variables presented in the methodology (Chapter II). The input data used in the test application (Chapter III) are listed with the input variables. In addition, general data source information is provided.

Input Variables

$MTBF_o$ = expected reliability level without warranty (test value: 400 hrs; source: contractor)

Alpha = reliability growth rate (test value: .40; source: contractor)

FW = estimated fraction of failures covered by warranty (test value: .95; source: Air Force)

DEL_i = delivered new engines for year i (test values: See Fig. 16; source: program)

W = warranty period in hours (test value: 500 hrs; source: warranty)

ERTS = fraction of engines repaired at base level (test value: .8; source: Air Force)

BMH or DMH = average manhours per repair at base or depot (test values: BMH = 250, DMH = 1100; source: Air Force or contractor)

BLA or DLA = warranty labor allowance rate at base or depot (test values: BLA = 14.00, DLA = 16.00; source: warranty)

OMX_i = inflation factor for year i (test values: see Fig. 16; source: Air Force)

BPA or DPA = average parts allowance per repair at base or depot level (test values: BPA = 15000.00, DPA = 65000.00; source: Air Force or contractor)

DR = discount rate (test value: .10; source: program)

FH_i = programmed flying hours per aircraft for year i (same as programmed flying hours per installed engine; test values: see Fig. 16; source: program)

GOR = ground operating rate (the ratio of engine ground operating time to flight time; test value: .1; source: Air Force)

EUR = engine utilization rate (the ratio of installed engines to total engines; test value: .8; source: Air Force)

ATR = attritions per engine operating hour (test value: .00001; source: Air Force)

$MTBF_i$ = expected mean time between failure for year i (test values: $MTBF_o$ and $MTBF_a$; source: contractor)

BMR = base consumable materials rate (nuts, washers, rags, etc., expressed as a cost per manhour; test value: 3.19; source: Air Force)

BRP = average cost of replacement parts per repair at base level (test value: 15000.00; source: Air Force)

BLR = base labor rate (cost per manhour; test value: 13.03; source: Air Force)

RMH = average manhours to remove and replace an engine (test value: 16 hrs; source: Air Force)

PSR = packing and shipping rate (cost per pound; test value: .59; source: Air Force)

EWT = engine and associated packaging weight (test value: 3100 lbs; source: contractor)

EOH = average cost of overhaul as a fraction of engine unit cost (test value: .10; source: Air Force)

EUC = engine unit cost (test value: 850000.00; source: contractor)

Year		DEL_i	OMX_i	FH_i
1978	1	100	1.061	1000
1979	2	200	1.117	1000
1980	3	200	1.165	1000
1981	4	150	1.210	1000
1982	5	100	1.258	1000
1983	6	0	1.307	1000
1984	7	0	1.358	1000
1985	8	0	1.411	1000
1986	9	0	1.457	1000
1987	10	0	1.506	1000
1988	11	0	1.555	1000
1989	12	0	1.605	1000
1990	13	0	1.654	1000
1991	14	0	1.703	1000
1992	15	0	1.752	1000

Figure 16. Annual Test Input Data

Computed Variables

$MTBF_{ai}$ = estimated warranty achieved MTBF for year i

WF_i = expected number of engine failures covered by the warranty for year i

NBR_i = number of base repairs for year i

NDR_i = number of depot repairs for year i

$LABOR_i$ = estimated annual labor penalty payments

BLP_i or DLP_i = base or depot labor penalty payments for year i

$PARTS_i$ = estimated annual parts penalty payments

BPP_i or DPP_i = base or depot parts penalty payments for year i

P_i = estimated penalty payment for year i

PVP_i = present value of P_i

DIS_i = discount factor for year i

P = total penalty payments (sum of P_is)

PVP = present value of P (sum of PVP_is)

EOP_i = expected engine operating hours per engine for year i

$ENGS_i$ = estimated number of engines in the inventory for year i

EF_i = estimated engine failures for year i

CBM = average cost of materials per repair at base level

BM_i = estimated cost of base materials for year i

CBL = average cost of labor per repair at base level

BL_i = estimated cost of base labor for year i

PSC_i = cost of packaging and shipping failed engines to the depot for overhaul for year i

COH = average cost of an engine overhaul

DC_i = failure related estimated depot cost for year i

LSC_i = expected engine logistics support cost for year i

R_i = estimated warranty reliability benefit for year i

$LSCO_i$ = logistics support cost at $MTBF_O$ for year i

$LSCA_i$	=	logistics support cost at $MTBF_a$ for year i
PVR_i	=	present value of P_i
R	=	total reliability benefit (sum of R_is)
PVR	=	present value of R (sum of PVR_is)
B	=	total warranty benefit (P + R)
PVB	=	total present value (PVP + PVR)

APPENDIX B

COST OF RELIABILITY GROWTH MODEL

The function for the cost of reliability growth used in this study was derived using an adaptation of a model developed by the Logistics Management Institute (LMI). This appendix contains a description of the Duane Growth Model upon which the LMI model is based (21:40) and a discussion of the LMI model and the way it was adapted for this research.

In 1962, J. T. Duane of the General Electric Motor and Generator Division published a paper postulating a model of reliability growth (8:459). Duane's findings resulted from

> . . . his analysis of test and operational data for programs with test times as high as 6 million hours on five divergent groups of products (two hydro-mechanical devices, two complex aircraft generators, and a jet engine) . . . [24:77].

His data indicated that during a continuous reliability improvement program, if the cumulative failure rate (defined as the total failures divided by the total test hours) is plotted against the total test hours on a log-log scale, the data approximate a straight line. The slope of that line is the reliability growth rate (alpha). Stated another way,

> . . . reliability improvement for complex equipment when operating in their [*sic*] intended use environment is approximately inversely proportional to the square root of the cumulative operating (test) time, and that for a constant level of corrective action effort and timely implementation, reliability gr wth closely approximates a straight line in log-log scales . . . [24:76-77].

The Duane model has been validated by independent users (21:38) and most have found that the slope of the reliability growth line is in the range of approximately 0.3 to 0.5 (8:460; 28:42). It is important to note that the reliability improvement effort must be continuous for the growth rate (alpha) to remain constant (8:459). However, failure definition is relatively unimportant to the slope of the reliability growth line; that is, differences in failure definition will shift the line vertically, but the slope will change very little, if at all (8:460).

LMI built upon the Duane model by assigning costs to the reliability growth program and constructing an equation for determining the cost of achieving a given reliability (MTBF) goal.

> The cost of achieving reliability is the sum of two fixed costs and two variable costs. The fixed costs include: (1) the basic cost of design and development which results in the production of prototype equipment for reliability testing and improvement; and (2) the basic acquisition cost of the prototype used for testing. The variable costs include: (1) the cost of testing; (2) the cost of design improvements; (3) the cost of parts improvements; and (4) the cost of quality control and production improvements. Using the Duane reliability growth equations, all of the variable costs are expressed as a function of MTBF [21:41].

The LMI model was modified in two ways for use in this study. First, the fixed costs (design cost and the cost of prototypes for testing) were assumed to be zero because it was assumed that a reliability growth

program would be a part of any engine development, but that the warranty had motivated the manufacturer to continue reliability growth on his own. Therefore, the basic design and hardware would already exist and the contractor's only costs would be the variable costs of continued testing and improvement.

Second, the LMI model provides a total cost to achieve a given level of reliability (MTBF), but because the manufacturer would only be paying for the additional reliability growth beyond the level already achieved ($MTBF_o$), the cost to achieve $MTBF_o$ was treated as zero. This was accomplished by subtracting the cost to achieve $MTBF_o$ from the cost of achieving any given level of reliability above $MTBF_o$. Thus, in the test application, the cost to achieve 400 hours MTBF is shown as zero. The cost of achieving 500 hours MTBF is the difference between the cost to achieve 400 hours MTBF and the cost to achieve 500 hours MTBF, not the total cost to grow an engine to 500 hours.

The costs were computed for values of MTBF at 25 hour intervals and then plotted for graphical representation. These costs were also used as the cost of reliability growth portion of the manufacturer's total cost function used to determine the reliability motivated by the warranty ($MTBF_a$).

APPENDIX C

COMPUTER PROGRAMS

```
C PENALTY PAYMENT MODEL *** DOOLEY & KELLS
C VARIABLES YR,DEL,OMX,FH ARE STORED IN FILE "YRDATA":
 CALL ATTACH(10,"77B60/YRDATA;",1,0,,)
 INTEGER YR,DEL
 REAL NBR,NDR,MTBFA,LABOR
C CONSTANTS ARE INPUT:
 DATA FW,ERTS,EUR,GOR/.95,.8,.8,.1/
 DATA BMH,BLA,BPA/250.,14.00,15000./
 DATA DMH,DLA,DPA/1100.,16.00,65000./
 PRINT 105
 105 FORMAT(////,20X,"***PENALTY PAYMENT MODEL***",///)
C VARIABLES W,MTBFA,AND DR ARE REQUESTED:
 PRINT,"     ENTER WARRANTY LEVEL(EG.=500.):"
 READ,W
 PRINT,"     ENTER WARRANTY ACHIEVED MTBF(EG.=750.):"
 READ,MTBFA
 PRINT,"     ENTER DISCOUNT RATE(EG.=.10):"
 READ,DR
 P=0.0;PVP=0.0
C HEADINGS FOR MODEL OUTPUT:
 PRINT 115
 115 FORMAT(///,4X,"ESTIMATED ANNUAL PENALTY PAYMENTS
& (IN MILLIONS):",//,8X,"YEAR  ENGS",4X,"LABOR",5X,"PARTS"
&,3X,"PEN PAY",6X,"PV")
C INPUT YR,DEL,OMX,FH FROM FILE "YRDATA":
 125 READ(10,135,END=95)LN,YR,DEL,OMX,FH
 135 FORMAT(V)
 IF(DEL.EQ.0)GO TO 125
C MODEL COMPUTATIONS:
 DIS=1/((1+DR)**YR)
 EOP=(FH*EUR)*(1+GOR)
 IF(W.GT.EOP) W=EOP
 WF=FW*DEL*(W/MTBFA)
 NBR=ERTS*WF
 NDR=WF-NBR
 BLP=NBR*BMH*BLA
 DLP=NDR*DMH*DLA
 LABOR=(BLP+DLP)/1000000.
 BPP=NBR*BPA
 DPP=NDR*DPA
 PARTS=((BPP+DPP)*OMX)/1000000.
 PI=LABOR+PARTS
 PVPI=PI*DIS
 P=P+PI
 PVP=PVP+PVPI
```

```
C ANNUAL OUTPUTS ARE PRINTED:
 PRINT 145,YR,DEL,LABOR,PARTS,PI,PVPI
 145 FORMAT(9X,I2,3X,I3,2X,F8.3,2X,F8.3,2X,F8.3,2X,F8.3)
C LOOP ADVANCES TO NEXT YEAR:
 GO TO 125
C WHEN ANNUAL COMPS ARE COMPLETE TOTAL IS PRINTED:
 95 PRINT 155,P,PVP
 155 FORMAT(//,4X,"TOTAL PENALTY PAYMENTS=",F9.3,
&" MILLION",//,4X,"TOTAL PRESENT VALUE=",F9.3," MILLION")
 STOP
 END
```

PENALTY PAYMENT MODEL

```
    ENTER WARRANTY LEVEL(EG.=500.):
=500.
    ENTER WARRANTY ACHIEVED MTBF(EG.=750.):
=425.
    ENTER DISCOUNT RATE(EG.=.10):
=.10
```

ESTIMATED ANNUAL PENALTY PAYMENTS (IN MILLIONS):

YEAR	ENGS	LABOR	PARTS	PEN PAY	PV
1	100	0.706	2.965	3.671	3.337
2	200	1.413	6.242	7.655	6.326
3	200	1.413	6.510	7.923	5.953
4	150	1.060	5.071	6.131	4.187
5	100	0.706	3.515	4.221	2.621

TOTAL PENALTY PAYMENTS= 29.601 MILLION

TOTAL PRESENT VALUE= 22.425 MILLION

```
C RELIABILITY BENEFIT MODEL *** DOOLEY & KELLS
C VARIABLES YR,DEL,OMX,FH ARE STORED IN FILE "YRDATA":
 CALL ATTACH(10,"77360/YRDATA;",1,0,,)
 INTEGER YR,ENGS,DEL
 REAL NBR,NDR,NBRA,NDRA,LSCO,LSCA,MTBFO,MTBFA
C CONSTANTS ARE INPUT:
 DATA ERTS,EUR,GOR,RMH,ATR/.8,.8,.1,16.0,.00001/
 DATA BMH,BLR,BMR,BRP/250.,13.03,3.19,15000./
 DATA EUC,EWT,EOH,PSR/850000.,3100.,.10,.59/
 PRINT 105
 105 FORMAT(////,18X,"***RELIABILITY BENEFIT MODEL***",///)
C VARIABLES MTBFO,MTBFA,AND DR ARE REQUESTED:
 PRINT,"      ENTER ORIGINAL MTBF(EG.=350.):"
 READ,MTBFO
 PRINT,"      ENTER WARRANTY ACHIEVED MTBF(EG.=750.):"
 READ,MTBFA
 PRINT,"      ENTER DISCOUNT RATE(EG.=.10):"
 READ,DR
 ENGS=0;R=0.0;PVR=0.0
C HEADINGS FOR MODEL OUTPUT:
 PRINT 115
 115 FORMAT(///,4X,"ESTIMATED ANNUAL RELIABILITY BENEFIT
& (IN MILLIONS):",//,8X,"YEAR  ENGS",4X,"LSCO",6X,"LSCA"
&,5X,"BENEFIT",5X,"PV")
C INPUT YR,DEL,OMX,FH FROM FILE "YRDATA":
 125 READ(10,135,END=95)LN,YR,DEL,OMX,FH
 135 FORMAT(V)
C MODEL COMPUTATIONS:
 DIS=1/((1+DR)**YR)
 EATR=ENGS*EOP*ATR
 EOP=(FH*EUR)*(1+GOR)
 ENGS=(ENGS-EATR)+DEL
C COMPUTATION OF LSCO:
 EF=ENGS*(EOP/MTBFO)
 NBR=ERTS*EF
 NDR=EF-NBR
 CBM=(BMH*BMR)+BRP
 BM=NBR*CBM
 CBL=BLR*(RMH+BMH)
 BL=NBR*CBL
 PSC=NDR*PSR*EWT
 COH=EOH*EUC
 DC=NDR*COH
 LSCO=((BM+BL+PSC+DC)*OMX)/1000000.
C COMPUTATION OF LSCA:
```

```
 EFA=ENGS*(EOP/MTBFA)
 NBRA=ERTS*EFA
 NDRA=EFA-NBRA
 BMA=NBRA*CBM
 BLA=NBRA*CBL
 PSCA=NDRA*PSR*EWT
 DCA=NDRA*COH
 LSCA=((BMA+BLA+PSCA+DCA)*OMX)/1000000.
C COMPUTATION OF RELIABILTY BENEFIT AND PV:
 RI=LSCO-LSCA
 PVRI=RI*DIS
 R=R+RI
 PVR=PVR+PVRI
C ANNUAL OUTPUTS ARE PRINTED:
 PRINT 145,YR,ENGS,LSCO,LSCA,RI,PVRI
 145 FORMAT(9X,I2,3X,I3,2X,F8.3,2X,F8.3,2X,F8.3,2X,F8.3)
C LOOP ADVANCES TO NEXT YEAR:
 GO TO 125
C WHEN ANNUAL COMPS ARE COMPLETE TOTAL IS PRINTED:
 95 PRINT 155,R,PVR
 155 FORMAT(//,4X,"TOTAL RELIABILITY BENEFIT=",F9.3,
&" MILLION",//,4X,"TOTAL PRESENT VALUE=",F9.3," MILLION")
 STOP
 END
```

RELIABILITY BENEFIT MODEL

```
   ENTER ORIGINAL MTBF(EG.=350.):
=400.
   ENTER WARRANTY ACHIEVED MTBF(EG.=750.):
=425.
   ENTER DISCOUNT RATE(EG.=.10):
=.10
```

ESTIMATED ANNUAL RELIABILITY BENEFIT (IN MILLIONS):

YEAR	ENGS	LSCO	LSCA	BENEFIT	PV
1	100	7.651	7.201	0.450	0.409
2	299	24.083	22.666	1.417	1.171
3	496	41.667	39.216	2.451	1.841
4	641	55.928	52.638	3.290	2.247
5	735	66.674	62.752	3.922	2.435
6	728	68.611	64.575	4.036	2.278
7	721	70.603	66.450	4.153	2.131
8	714	72.646	68.373	4.273	1.994
9	707	74.279	69.910	4.369	1.853
10	700	76.017	71.545	4.472	1.724
11	693	77.705	73.134	4.571	1.602
12	686	79.394	74.723	4.670	1.488
13	679	80.983	76.219	4.764	1.380
14	673	82.645	77.783	4.861	1.280
15	667	84.265	79.308	4.957	1.187

TOTAL RELIABILITY BENEFIT= 56.656 MILLION

TOTAL PRESENT VALUE= 25.020 MILLION

```
C GROWTH COST SENSITIVITY TO ALPHA **** DOOLEY & KELLS
C OUTPUT IS STORED IN FILE "GVARA"
 CALL ATTACH(20,"77B60/GVARA;",3,0,,)
 REAL TESTHRS,C1,C2P2,C3P3,C4P4
 REAL LO,HI,MAX,MTBFO,ENGS,K,MTBFA,ALPHA
C CONSTANTS ARE INPUT
 DATA TESTHRS,C1/12000.,700./
 DATA C2P2,C3P3,C4P4,ENGS/25000.,750.,150.,750./
 PRINT 50
 50 FORMAT(////,5X,"**SENSITIVITY OF RELIABILITY GROWTH
& COST TO ALPHA**",///)
C VARIABLES ARE REQUESTED
 PRINT,"ENTER RANGE OF ALPHA  (E.G. = .40,.60) "
 READ,LO,HI
 PRINT,"ENTER MTBFO TO NEAREST 25 HOURS (E.G. = 300.)"
 READ,MTBFO
 PRINT,"ENTER HIGHEST EXPECTED MTBFA TO NEAREST 25
& HOURS (E.G. = 800.)"
 READ,MAX
 PRINT 70
 70 FORMAT(///,18X,"COST TO ACHIEVE MTBFA (IN MILLIONS)
&",//,18X,"ALPHA",4X,"CONST",4X,"MTBFA",6X,"COST",)
 ALPHA = LO
C MODEL COMPUTATIONS BEGIN
 80 K = 1./(MTBFO*TESTHRS**(0.0-ALPHA))
 T1 = (MTBFO*(1.-ALPHA)*K) ** (1./ALPHA)
 T2 = C2P2 +ENGS*(C3P3+C4P4)
 T3 = (1.-ALPHA)*MTBFO
 COSTRELO = T1*(T2/T3 + C1)
 MTBFA = MTBFO
 90 T1A =(MTBFA*(1.-ALPHA)*K) **(1./ALPHA)
 T3A = (1.-ALPHA)*MTBFA
 COSTRELA = T1A*(T2/T3A + C1)
 COST = (COSTRELA-COSTRELO)/1000000.
 PRINT 100,ALPHA,K,MTBFA,COST
 WRITE(20,100) ALPHA,K,MTBFA,COST
 100 FORMAT(18X,F4.2,5X,F5.3,4X,F5.0,4X,F8.3)
 MTBFA = MTBFA+25.
 IF(MTBFA.LE.MAX)GO TO 90
 ALPHA = ALPHA+0.10
 IF(ALPHA.LE.HI)GO TO 80
 STOP
 END
```

AD-A047 282 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC F/G 14/1
A METHODOLOGY FOR ESTIMATING THE ECONOMIC BENEFITS OF AN AIRCRA--ETC(U)
SEP 77 M P DOOLEY, R E KELLS

UNCLASSIFIED AFIT-LSSR-10-77B NL

2 OF 2
ADA047282

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SENSITIVITY OF RELIABILITY GROWTH COST TO ALPHA

```
ENTER RANGE OF ALPHA  (E.G. = .40,.60)
=.30,.50
ENTER MTBFO TO NEAREST 25 HOURS (E.G. = 300.)
=400.
ENTER HIGHEST EXPECTED MTBFA TO NEAREST 25 HOURS (E.G. = 800.)
=500.
```

COST TO ACHIEVE MTBFA (IN MILLIONS)

ALPHA	CONST	MTBFA	COST
0.30	0.042	400.	0.000
0.30	0.042	425.	1.961
0.30	0.042	450.	4.120
0.30	0.042	475.	6.485
0.30	0.042	500.	9.066
0.40	0.107	400.	-0.000
0.40	0.107	425.	1.312
0.40	0.107	450.	2.688
0.40	0.107	475.	4.127
0.40	0.107	500.	5.630
0.50	0.274	400.	0.
0.50	0.274	425.	0.927
0.50	0.274	450.	1.870
0.50	0.274	475.	2.830
0.50	0.274	500.	3.806

```
C P SENSITIVITY TO MTBFA *** DOOLEY & KELLS
C VARIABLES YR,DEL,OMX,FH ARE STORED IN FILE "YRDATA":
 CALL ATTACH(10,"77B60/YRDATA;",1,0,,)
C OUTPUT FILED IN FILE "PVARM":
 CALL ATTACH(20,"77B60/PVARM;",3,0,,)
 INTEGER YR,DEL
 REAL NBR,NDR,MTBFA,LABOR,LOW
C CONSTANTS ARE INPUT:
 DATA FW,ERTS,EUR,GOR/.95,.8,.8,.1/
 DATA BMH,BLA,BPA/250.,14.00,15000./
 DATA DMH,DLA,DPA/1100.,16.00,65000./
 PRINT 105
 105 FORMAT(////,18X,"***P SENSITIVITY TO MTBFA***",///)
C VARIABLES W,DR,AND MTBFA RANGE ARE REQUESTED:
 PRINT,"     ENTER WARRANTY LEVEL(EG.=500.):"
 READ,W
 PRINT,"     ENTER DISCOUNT RATE(EG.=.10):"
 READ,DR
 PRINT 110
 110 FORMAT(5X,"ENTER LOWEST AND HIGHEST EXPECTED MTBFA
& TO THE",/,"          NEAREST 5 HOURS(EG.=415.,655.):")
 READ,LOW,HIGH
 MTBFA=LOW-5.
C HEADINGS FOR MODEL OUTPUT:
 PRINT 115
 115 FORMAT(///,12X,"PENALTY PAYMENTS (IN MILLIONS):",//,
&18X,"MTBFA",6X,"P",8X,"PV")
C START OUTER LOOP:
 120 MTBFA=MTBFA+5.
 IF(MTBFA.GT.HIGH) GO TO 85
 P=0.0;PVP=0.0
C INPUT YR,DEL,OMX,FH FROM FILE "YRDATA":
 125 READ(10,135,END=95)LN,YR,DEL,OMX,FH
 135 FORMAT(V)
 IF(DEL.EQ.0)GO TO 125
C MODEL COMPUTATIONS:
 DIS=1/((1+DR)**YR)
 EOP=(FH*EUR)*(1+GOR)
 IF(W.GT.EOP) W=EOP
 WF=FW*DEL*(W/MTBFA)
 NBR=ERTS*WF
 NDR=WF-NBR
 BLP=NBR*BMH*BLA
 DLP=NDR*DMH*DLA
 LABOR=(BLP+DLP)/1000000.
```

```
 BPP=NBR*BPA
 DPP=NDR*DPA
 PARTS=((BPP+DPP)*OMX)/1000000.
 PI=LABOR+PARTS
 PVPI=PI*DIS
 P=P+PI
 PVP=PVP+PVPI
C LOOP ADVANCES TO NEXT YEAR:
 GO TO 125
C WHEN ANNUAL COMPS ARE COMPLETE TOTAL IS PRINTED:
 95 PRINT 155,MTBFA,P,PVP
 155 FORMAT(18X,F5.0,2X,F8.3,2X,F8.3)
 WRITE(20,155)MTBFA,P,PVP
 REWIND 10
C OUTER LOOP ADVANCES TO NEXT SENSITIVITY VALUE:
 GO TO 120
 85 STOP
 END
```

P SENSITIVITY TO MTBFA

```
    ENTER WARRANTY LEVEL(EG.=500.):
=500.
    ENTER DISCOUNT RATE(EG.=.10):
=.10
    ENTER LOWEST AND HIGHEST EXPECTED MTBFA TO THE
    NEAREST 5 HOURS(EG.=415.,655.):
=400.,475.
```

PENALTY PAYMENTS (IN MILLIONS):

MTBFA	P	PV
400.	31.451	23.826
405.	31.063	23.532
410.	30.684	23.245
415.	30.314	22.965
420.	29.953	22.692
425.	29.601	22.425
430.	29.257	22.164
435.	28.920	21.909
440.	28.592	21.660
445.	28.271	21.417
450.	27.956	21.179
455.	27.649	20.946
460.	27.349	20.718
465.	27.055	20.496
470.	26.767	20.278
475.	26.485	20.064

```
C R SENSITIVITY TO MTBFA *** DOOLEY & KELLS
C VARIABLES YR,DEL,OMX,FH ARE STORED IN FILE "YRDATA":
 CALL ATTACH(10,"77B60/YRDATA;",1,0,,)
C OUTPUT FILED IN FILE "RVARM":
 CALL ATTACH(20,"77B60/RVARM;",3,0,,)
 INTEGER YR,ENGS,DEL
 REAL NBR,NDR,NBRA,NDRA,LSCO,LSCA,MTBFO,MTBFA,LOW
C CONSTANTS ARE INPUT:
 DATA ERTS,EUR,GOR,RMH,ATR/.8,.8,.1,16.0,.00001/
 DATA BMH,BLR,BMR,BRP/250.,13.03,3.19,15000./
 DATA EUC,EWT,EOH,PSR/850000.,3100.,.10,.59/
 PRINT 105
 105 FORMAT(////,13X,"***R SENSITIVITY TO MTBFA***",///)
C VARIABLES MTBFO,DR,AND MTBFA RANGE ARE REQUESTED:
 PRINT,"      ENTER ORIGINAL MTBF(EG.=350.):"
 READ,MTBFO
 PRINT,"      ENTER DISCOUNT RATE(EG.=.10):"
 READ,DR
 PRINT 107
 107 FORMAT(5X,"ENTER LOWEST AND HIGHEST EXPECTED MTBFA
& TO THE",/,"          NEAREST 5 HOURS(EG.=415.,655.):")
 READ,LOW,HIGH
 MTBFA=LOW-5.
C HEADINGS FOR MODEL OUTPUT:
 PRINT 115
 115 FORMAT(///,12X,"RELIABILITY BENEFIT (IN MILLIONS):",//,
&18X,"MTBFA",6X,"R",8X,"PV")
C START OF OUTER LOOP:
 120 MTBFA=MTBFA+5.
 IF(MTBFA.GT.HIGH) GO TO 85
 ENGS=0;R=0.0;PVR=0.0
C INPUT YR,DEL,OMX,FH FROM FILE "YRDATA":
 125 READ(10,135,END=95)LN,YR,DEL,OMX,FH
 135 FORMAT(V)
C MODEL COMPUTATIONS:
 DIS=1/((1+DR)**YR)
 EATR=ENGS*EOP*ATR
 EOP=(FH*EUR)*(1+GOR)
 ENGS=(ENGS-EATR)+DEL
C COMPUTATION OF LSCO:
 EF=ENGS*(EOP/MTBFO)
 NBR=ERTS*EF
 NDR=EF-NBR
 CBM=(BMH*BMR)+BRP
 BM=NBR*CBM
```

```
 CBL=BLR*(RMH+BMH)
 BL=NBR*CBL
 PSC=NDR*PSR*EWT
 COH=EOH*EUC
 DC=NDR*COH
 LSCO=((BM+BL+PSC+DC)*OMX)/1000000.
C COMPUTATION OF LSCA:
 EFA=ENGS*(EOP/MTBFA)
 NBRA=ERTS*EFA
 NDRA=EFA-NBRA
 BMA=NBRA*CBM
 BLA=NBRA*CBL
 PSCA=NDRA*PSR*EWT
 DCA=NDRA*COH
 LSCA=((BMA+BLA+PSCA+DCA)*OMX)/1000000.
C COMPUTATION OF RELIABILTY BENEFIT AND PV:
 RI=LSCO-LSCA
 PVRI=RI*DIS
 R=R+RI
 PVR=PVR+PVRI
C LOOP ADVANCES TO NEXT YEAR:
 GO TO 125
C WHEN ANNUAL COMPS ARE COMPLETE TOTAL IS PRINTED:
 95 PRINT 155,MTBFA,R,PVR
 155 FORMAT(18X,F5.0,2X,F8.3,2X,F8.3)
 WRITE(20,155)MTBFA,R,PVR
 REWIND 10
C OUTER LOOP ADVANCES TO NEXT SENSITIVITY VALUE:
 GO TO 120
 85 STOP
 END
```

R SENSITIVITY TO MTBFA

```
    ENTER ORIGINAL MTBF(EG.=350.):
=400.
    ENTER DISCOUNT RATE(EG.=.10):
=.10
    ENTER LOWEST AND HIGHEST EXPECTED MTBFA TO THE
    NEAREST 5 HOURS(EG.=415.,655.):
=400.,475.
```

RELIABILITY BENEFIT (IN MILLIONS):

MTBFA	R	PV
400.	-0.000	-0.000
405.	11.891	5.251
410.	23.491	10.374
415.	34.813	15.374
420.	45.864	20.255
425.	56.656	25.020
430.	67.196	29.675
435.	77.495	34.223
440.	87.559	38.668
445.	97.397	43.013
450.	107.017	47.261
455.	116.425	51.416
460.	125.628	55.480
465.	134.634	59.457
470.	143.448	63.349
475.	152.076	67.160

```
C TOTAL BENEFIT SENSITIVITY TO MTBFA ** * DOOLEY & KELLS
C INPUT FROM FILES "RVARM" AND "PVARM":
 CALL ATTACH(10,"77B60/RVARM;",1,0,,)
 CALL ATTACH(15,"77B60/PVARM;",1,0,,)
C OUTPUT FILED IN FILE "BVARM":
 CALL ATTACH(20,"77B60/BVARM;",3,0,,)
 REAL MTBFA,MTBFAP
C HEADINGS ARE PRINTED:
 PRINT 105
 105 FORMAT(////,16X,"***TOTAL BENEFIT SENSITIVITY TO MTBFA
&***")
 PRINT 115
 115 FORMAT(///,2X,"BENEFIT VALUES (IN MILLIONS):",//,
&4X,"MTBFA",6X,"R",8X,"PVR",8X,"P",8X,"PVP",9X,"B",9X,"PVB")
C INPUT MTBFA,R,PVR,P,PVP FROM FILES "RVARM" AND "PVARM":
 125 READ(10,135,END=95)MTBFA,R,PVR
 135 FORMAT(V)
 READ(15,135)MTBFAP,P,PVP
 IF(MTBFA.NE.MTBFAP)GO TO 85
C MODEL COMPUTATIONS:
 B=R+P
 PVB=PVR+PVP
C PRINT AND FILE OUTPUT:
 PRINT 145,MTBFA,R,PVR,P,PVP,B,PVB
 145 FORMAT(4X,F5.0,4(2X,F8.3),2(2X,F9.3))
 WRITE(20,145)MTBFA,R,PVR,P,PVP,B,PVB
 GO TO 125
 85 PRINT,"    MTBFA RANGES ARE NOT COMPATIBLE - CHECK INPUT
& FILES"
 95 STOP
 END
```

TOTAL BENEFIT SENSITIVITY TO MTBFA

BENEFIT VALUES (IN MILLIONS):

MTBFA	R	PVR	P	PVP	B	PVB
400.	0.	0.	31.451	23.826	31.451	23.826
405.	11.891	5.251	31.063	23.532	42.954	28.783
410.	23.491	10.374	30.684	23.245	54.175	33.619
415.	34.813	15.374	30.314	22.965	65.127	38.339
420.	45.864	20.255	29.953	22.692	75.817	42.947
425.	56.656	25.020	29.601	22.425	86.257	47.445
430.	67.196	29.675	29.257	22.164	96.453	51.839
435.	77.495	34.223	28.920	21.909	106.415	56.132
440.	87.559	38.668	28.592	21.660	116.151	60.328
445.	97.397	43.013	28.271	21.417	125.668	64.430
450.	107.017	47.261	27.956	21.179	134.973	68.440
455.	116.425	51.416	27.649	20.946	144.074	72.362
460.	125.628	55.480	27.349	20.718	152.977	76.198
465.	134.634	59.457	27.055	20.496	161.689	79.953
470.	143.448	63.349	26.767	20.278	170.215	83.627
475.	152.076	67.160	26.485	20.064	178.561	87.224

```
C P SENSITIVITY TO DISCOUNT RATE *** DOOLEY & KELLS
C VARIABLES YR,DEL,OMX,FH ARE STORED IN FILE "YRDATA":
 CALL ATTACH(10,"77B60/YRDATA;",1,0,,)
C OUTPUT FILED IN FILE "PVARD":
 CALL ATTACH(20,"77B60/PVARD;",3,0,,)
 INTEGER YR,DEL
 REAL NBR,NDR,MTBFA,LABOR,LOW
C CONSTANTS ARE INPUT:
 DATA FW,ERTS,EUR,GOR/.95,.8,.8,.1/
 DATA BMH,BLA,BPA/250.,14.00,15000./
 DATA DMH,DLA,DPA/1100.,16.00,65000./
 PRINT 105
 105 FORMAT(////,18X,"***P SENSITIVITY TO DISCOUNT RATE***"
&,///)
C VARIABLES W,MTBFA,AND DR RANGE ARE REQUESTED:
 PRINT,"     ENTER WARRANTY LEVEL(EG.=500.):"
 READ,W
 PRINT,"     ENTER ACHIEVED MTBF(EG.=750.):"
 READ,MTBFA
 PRINT 110
 110 FORMAT(5X,"ENTER LOWEST AND HIGHEST DISCOUNT RATE TO
& THE",/,"       NEAREST .01(EG.=.05,.15):")
 READ,LOW,HIGH
 DR=LOW-.01
C HEADINGS FOR MODEL OUTPUT:
 PRINT 115
 115 FORMAT(///,12X,"PENALTY PAYMENTS (IN MILLIONS):",//,
&19X,"DR",9X,"P",8X,"PV")
C START OUTER LOOP:
 120 DR=DR+.01
 IF(DR.GT.HIGH)GO TO 85
 P=0.0;PVP=0.0
C INPUT YR,DEL,OMX,FH FROM FILE "YRDATA":
 125 READ(10,135,END=95)LN,YR,DEL,OMX,FH
 135 FORMAT(V)
 IF(DEL.EQ.0)GO TO 125
C MODEL COMPUTATIONS:
 DIS=1/((1+DR)**YR)
 EOP=(FH*EUR)*(1+GOR)
 IF(W.GT.EOP)W=EOP
 WF=FW*DEL*(W/MTBFA)
 NBR=ERTS*WF
 NDR=WF-NBR
 BLP=NBR*BMH*BLA
 DLP=NDR*DMH*DLA
```

```
 LABOR=(BLP+DLP)/1000000.
 BPP=NBR*BPA
 DPP=NDR*DPA
 PARTS=((BPP+DPP)*OMX)/1000000.
 PI=LABOR+PARTS
 PVPI=PI*DIS
 P=P+PI
 PVP=PVP+PVPI
C LOOP ADVANCES TO NEXT YEAR:
 GO TO 125
C WHEN ANNUAL COMPS ARE COMPLETE TOTAL IS PRINTED:
 95 PRINT 155,DR,P,PVP
 155 FORMAT(18X,F4.2,4X,F8.3,2X,F8.3)
 WRITE(20,155)DR,P,PVP
 REWIND 10
C OUTER LOOP ADVANCES TO NEXT SENSITIVITY VALUE:
 GO TO 120
 85 STOP
 END
```

```
***P SENSITIVITY TO DISCOUNT RATE***

    ENTER WARRANTY LEVEL(EG.=500.):
=500.
    ENTER ACHIEVED MTBF(EG.=750.):
=425.
    ENTER LOWEST AND HIGHEST DISCOUNT RATE TO THE
    NEAREST .01(EG.=.05,.15):
=.00,.15
```

PENALTY PAYMENTS (IN MILLIONS):

DR	P	PV
0.	29.601	29.601
0.01	29.601	28.737
0.02	29.601	27.910
0.03	29.601	27.119
0.04	29.601	26.361
0.05	29.601	25.635
0.06	29.601	24.939
0.07	29.601	24.271
0.08	29.601	23.631
0.09	29.601	23.016
0.10	29.601	22.425
0.11	29.601	21.857
0.12	29.601	21.311
0.13	29.601	20.786
0.14	29.601	20.280
0.15	29.601	19.794

```
C R SENSITIVITY TO DISCOUNT RATE *** DOOLEY & KELLS
C VARIABLES YR,DEL,OMX,FH ARE STORED IN FILE "YRDATA":
 CALL ATTACH(10,"77B60/YRDATA;",1,0,,)
C OUTPUT FILED IN FILE "RVARD":
 CALL ATTACH(20,"77B60/RVARD;",3,0,,)
 INTEGER YR,ENGS,DEL
 REAL NBR,NDR,NBRA,NDRA,LSCO,LSCA,MTBFO,MTBFA,LOW
C CONSTANTS ARE INPUT:
 DATA ERTS,EUR,GOR,RMH,ATR/.8,.8,.1,16.0,.00001/
 DATA BMH,BLR,BMR,BRP/250.,13.03,3.19,15000./
 DATA EUC,EWT,EOH,PSR/850000.,3100.,.10,.59/
 PRINT 105
 105 FORMAT(////,16X,"***R SENSITIVITY TO DISCOUNT RATE***"
&,///)
C VARIABLES MTBFO,MTBFA,AND DR RANGE ARE REQUESTED:
 PRINT,"     ENTER ORIGINAL MTBF(EG.=350.):"
 READ,MTBFO
 PRINT,"     ENTER ACHIEVED MTBF(EG.=750.):"
 READ,MTBFA
 PRINT 107
 107 FORMAT(5X,"ENTER LOWEST AND HIGHEST DISCOUNT RATE TO
& THE",/,"         NEAREST .01(EG.=.05,.15):")
 READ,LOW,HIGH
 DR=LOW-.01
C HEADINGS FOR MODEL OUTPUT:
 PRINT 115
 115 FORMAT(///,12X,"RELIABILITY BENEFIT (IN MILLIONS):",//,
&19X,"DR",9X,"R",8X,"PV")
C START OF OUTER LOOP:
 120 DR=DR+.01
 IF(DR.GT.HIGH)GO TO 85
 ENGS=0;R=0.0;PVR=0.0
C INPUT YR,DEL,OMX,FH FROM FILE "YRDATA":
 125 READ(10,135,END=95)LN,YR,DEL,OMX,FH
 135 FORMAT(V)
C MODEL COMPUTATIONS:
 DIS=1/((1+DR)**YR)
 EATR=ENGS*EOP*ATR
 EOP=(FH*EUR)*(1+GOR)
 ENGS=(ENGS-EATR)+DEL
C COMPUTATION OF LSCO:
 EF=ENGS*(EOP/MTBFO)
 NBR=ERTS*EF
 NDR=EF-NBR
 CBM=(BMH*BMR)+BRP
```

```
 BM=NBR*CBM
 CBL=BLR*(RMH+BMH)
 BL=NBR*CBL
 PSC=NDR*PSR*EWT
 COH=EOH*EUC
 DC=NDR*COH
 LSCO=((BM+BL+PSC+DC)*OMX)/1000000.
C COMPUTATION OF LSCA:
 EFA=ENGS*(EOP/MTBFA)
 NBRA=ERTS*EFA
 NDRA=EFA-NBRA
 BMA=NBRA*CBM
 BLA=NBRA*CBL
 PSCA=NDRA*PSR*EWT
 DCA=NDRA*COH
 LSCA=((BMA+BLA+PSCA+DCA)*OMX)/1000000.
C COMPUTATION OF RELIABILTY BENEFIT AND PV:
 RI=LSCO-LSCA
 PVRI=RI*DIS
 R=R+RI
 PVR=PVR+PVRI
C LOOP ADVANCES TO NEXT YEAR:
 GO TO 125
C WHEN ANNUAL COMPS ARE COMPLETE TOTAL IS PRINTED:
 95 PRINT 155,DR,R,PVR
 155 FORMAT(18X,F4.2,4X,F8.3,2X,F8.3)
 WRITE(20,155)DR,R,PVR
 REWIND 10
C OUTER LOOP ADVANCES TO NEXT SENSITIVITY VALUE:
 GO TO 120
 85 STOP
 END
```

```
***R SENSITIVITY TO DISCOUNT RATE***

     ENTER ORIGINAL MTBF(EG.=350.):
=400.
     ENTER ACHIEVED MTBF(EG.=750.):
=425.
     ENTER LOWEST AND HIGHEST DISCOUNT RATE TO THE
     NEAREST .01(EG.=.05,.15):
=.00,.15


           RELIABILITY BENEFIT (IN MILLIONS):

                DR          R          PV
                0.        56.656     56.656
                0.01      56.656     51.698
                0.02      56.656     47.283
                0.03      56.656     43.345
                0.04      56.656     39.823
                0.05      56.656     36.667
                0.06      56.656     33.832
                0.07      56.656     31.281
                0.08      56.656     28.981
                0.09      56.656     26.902
                0.10      56.656     25.020
                0.11      56.656     23.313
                0.12      56.656     21.761
                0.13      56.656     20.348
                0.14      56.656     19.059
                0.15      56.656     17.881
```

```
C TOTAL BENEFIT SENSITIVITY TO DR ** * DOOLEY & KELLS
C INPUT FROM FILES "RVARD" AND "PVARD":
 CALL ATTACH(10,"77B60/RVARD;",1,0,,)
 CALL ATTACH(15,"77B60/PVARD;",1,0,,)
C OUTPUT FILED IN FILE "BVARD":
 CALL ATTACH(20,"77B60/BVARD;",3,0,,)
C HEADINGS ARE PRINTED:
 PRINT 105
 105 FORMAT(////,16X,"***TOTAL BENEFIT SENSITIVITY TO DR
&***")
 PRINT 115
 115 FORMAT(///,2X,"BENEFIT VALUES (IN MILLIONS):",//,
&6X,"DR",7X,"R",8X,"PVR",8X,"P",8X,"PVP",9X,"B",9X,"PVB")
C INPUT DR,R,PVR,P,PVP FROM FILES "RVARD" AND "PVARD":
 125 READ(10,135,END=95)DR,R,PVR
 135 FORMAT(V)
 READ(15,135)DRP,P,PVP
 IF(DR.NE.DRP)GO TO 85
C MODEL COMPUTATIONS:
 B=R+P
 PVB=PVR+PVP
C PRINT AND FILE OUTPUT:
 PRINT 145,DR,R,PVR,P,PVP,B,PVB
 145 FORMAT(5X,F4.2,4(2X,F8.3),2(2X,F9.3))
 WRITE(20,145)DR,R,PVR,P,PVP,B,PVB
 GO TO 125
 85 PRINT,"    DR RANGES ARE NOT COMPATIBLE - CHECK INPUT
& FILES"
 95 STOP
 END
```

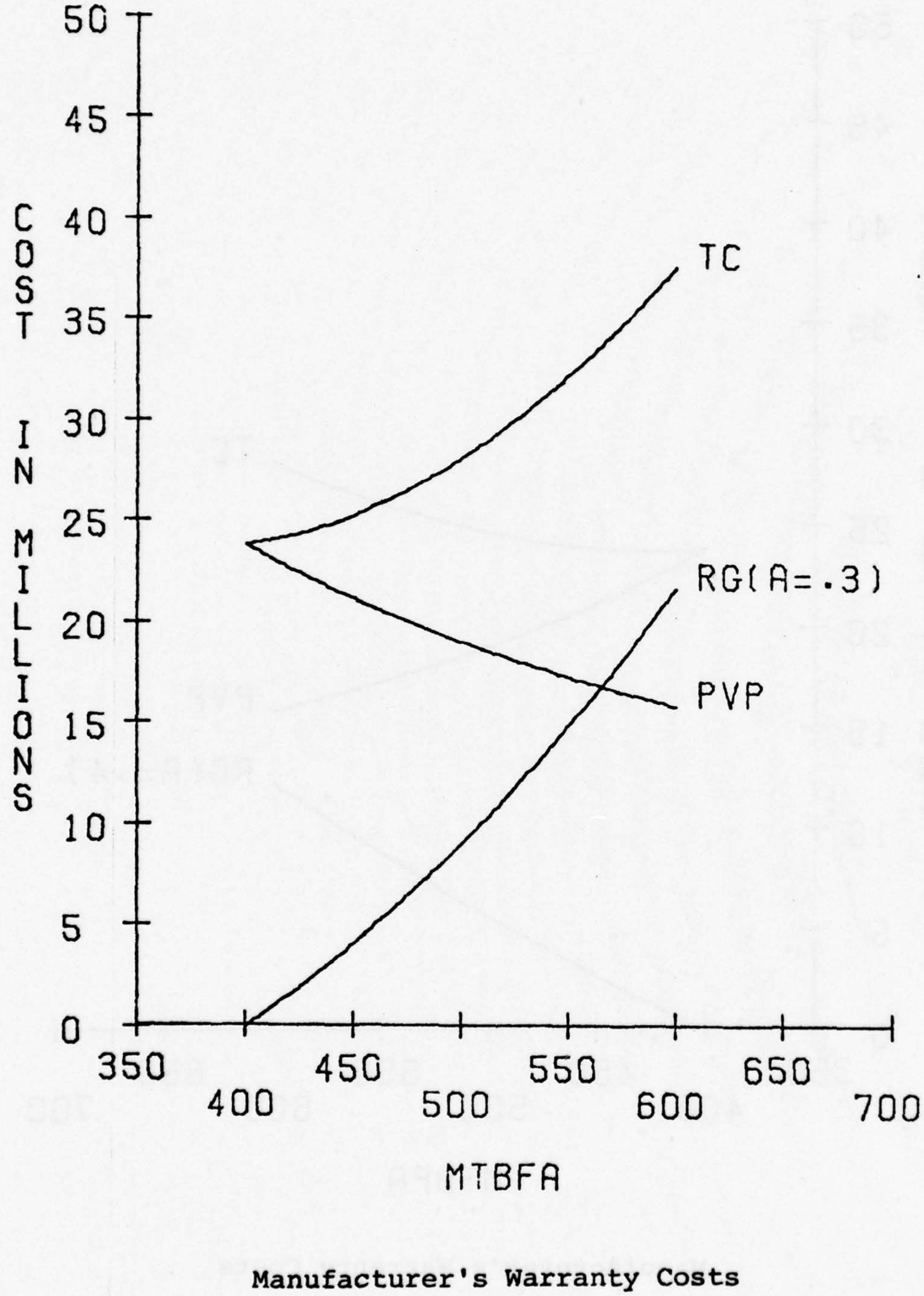
TOTAL BENEFIT SENSITIVITY TO DR

BENEFIT VALUES (IN MILLIONS):

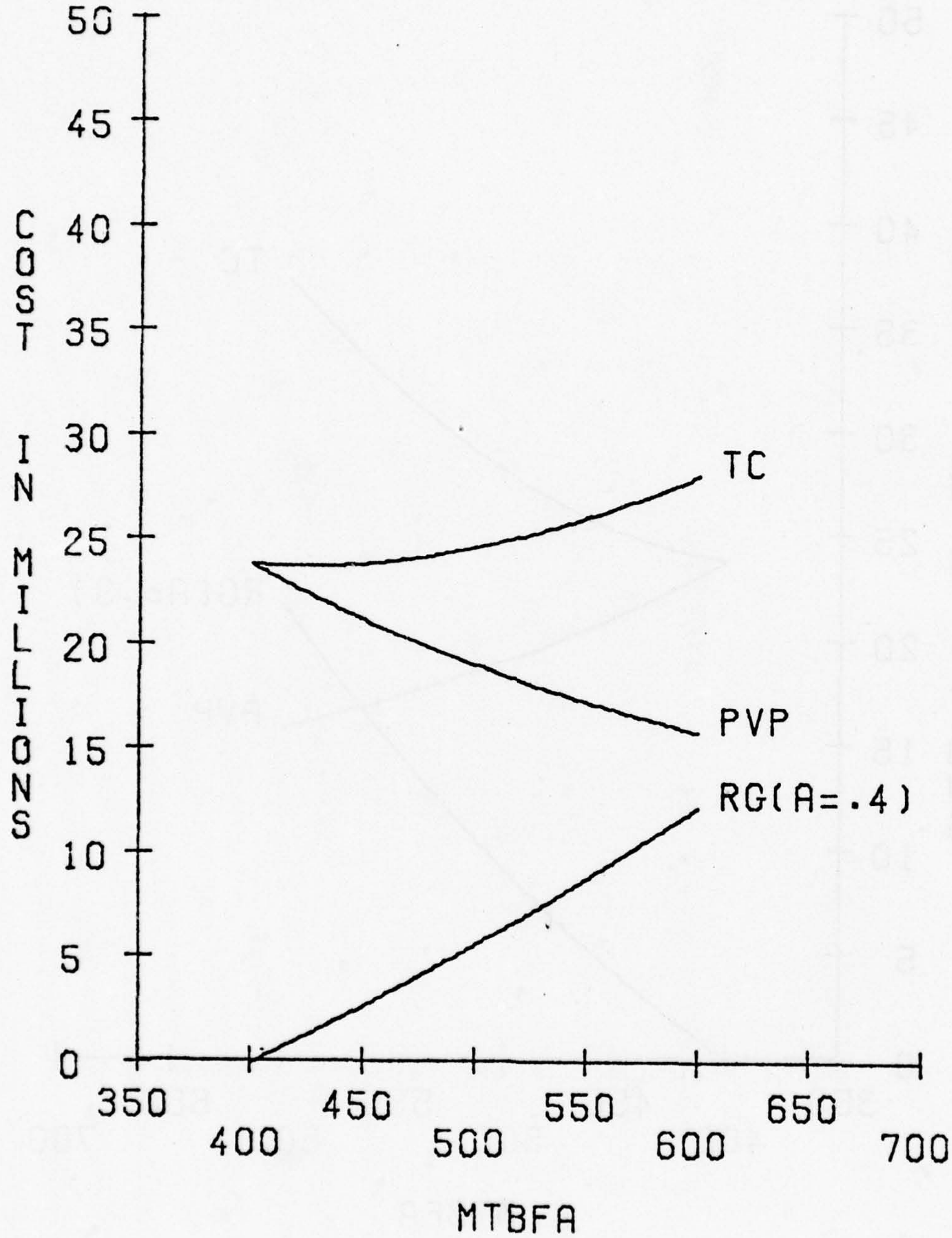
DR	R	PVR	P	PVP	B	PVB
Ø.	56.656	56.656	29.6Ø1	29.6Ø1	86.257	86.257
Ø.Ø1	56.656	51.698	29.6Ø1	28.737	86.257	8Ø.435
Ø.Ø2	56.656	47.283	29.6Ø1	27.91Ø	86.257	75.193
Ø.Ø3	56.656	43.345	29.6Ø1	27.119	86.257	7Ø.464
Ø.Ø4	56.656	39.823	29.6Ø1	26.361	86.257	66.184
Ø.Ø5	56.656	36.667	29.6Ø1	25.635	86.257	62.3Ø2
Ø.Ø6	56.656	33.832	29.6Ø1	24.939	86.257	58.771
Ø.Ø7	56.656	31.281	29.6Ø1	24.271	86.257	55.552
Ø.Ø8	56.656	28.981	29.6Ø1	23.631	86.257	52.612
Ø.Ø9	56.656	26.9Ø2	29.6Ø1	23.Ø16	86.257	49.918
Ø.1Ø	56.656	25.Ø2Ø	29.6Ø1	22.425	86.257	47.445
Ø.11	56.656	23.313	29.6Ø1	21.857	86.257	45.17Ø
Ø.12	56.656	21.751	29.6Ø1	21.311	86.257	43.Ø72
Ø.13	56.656	2Ø.343	29.6Ø1	2Ø.786	86.257	41.134
Ø.14	56.656	19.Ø59	29.6Ø1	2Ø.28Ø	86.257	39.339
Ø.15	56.656	17.881	29.6Ø1	19.794	86.257	37.675

APPENDIX D

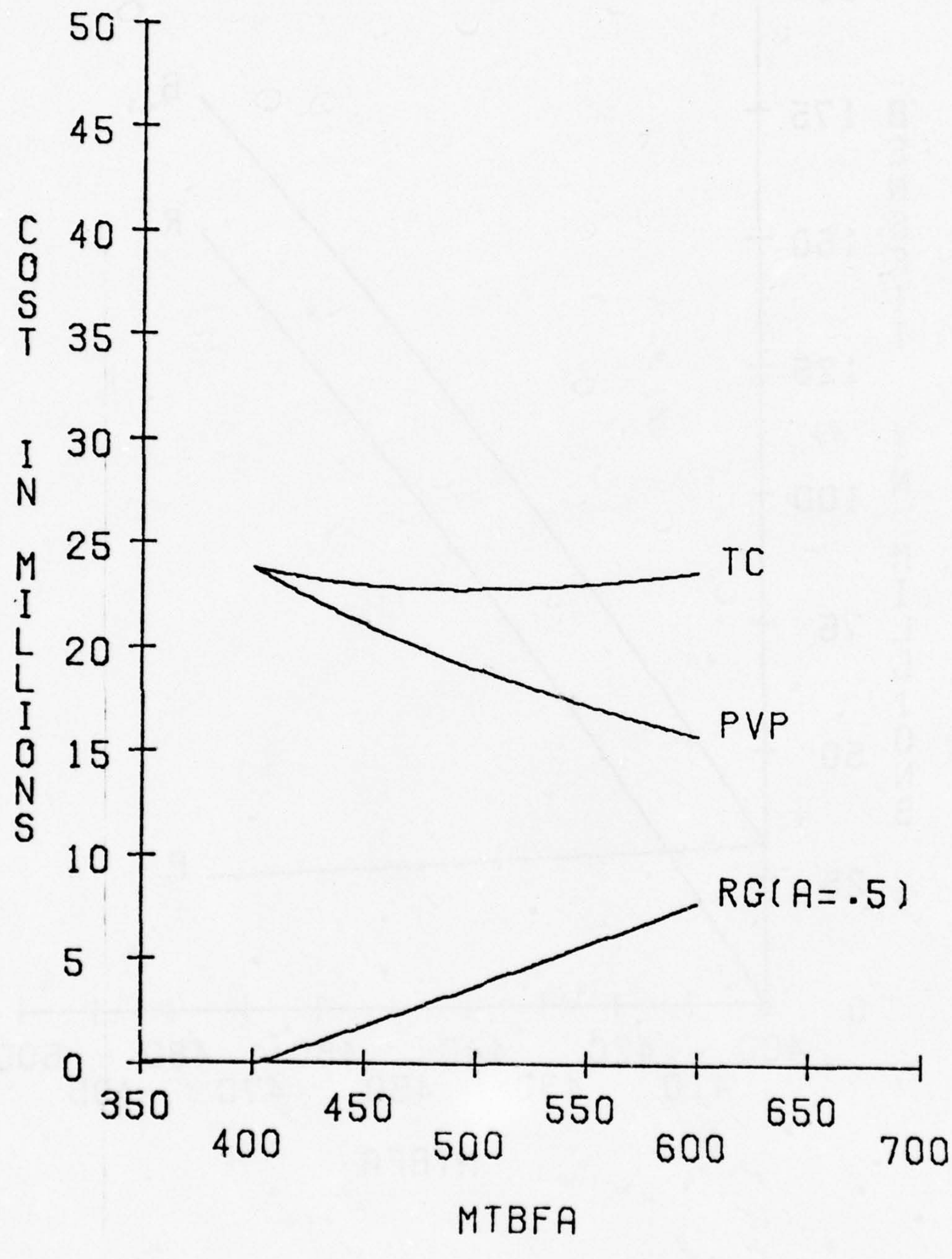
SENSITIVITY GRAPHS



Manufacturer's Warranty Costs
(Alpha = .3)

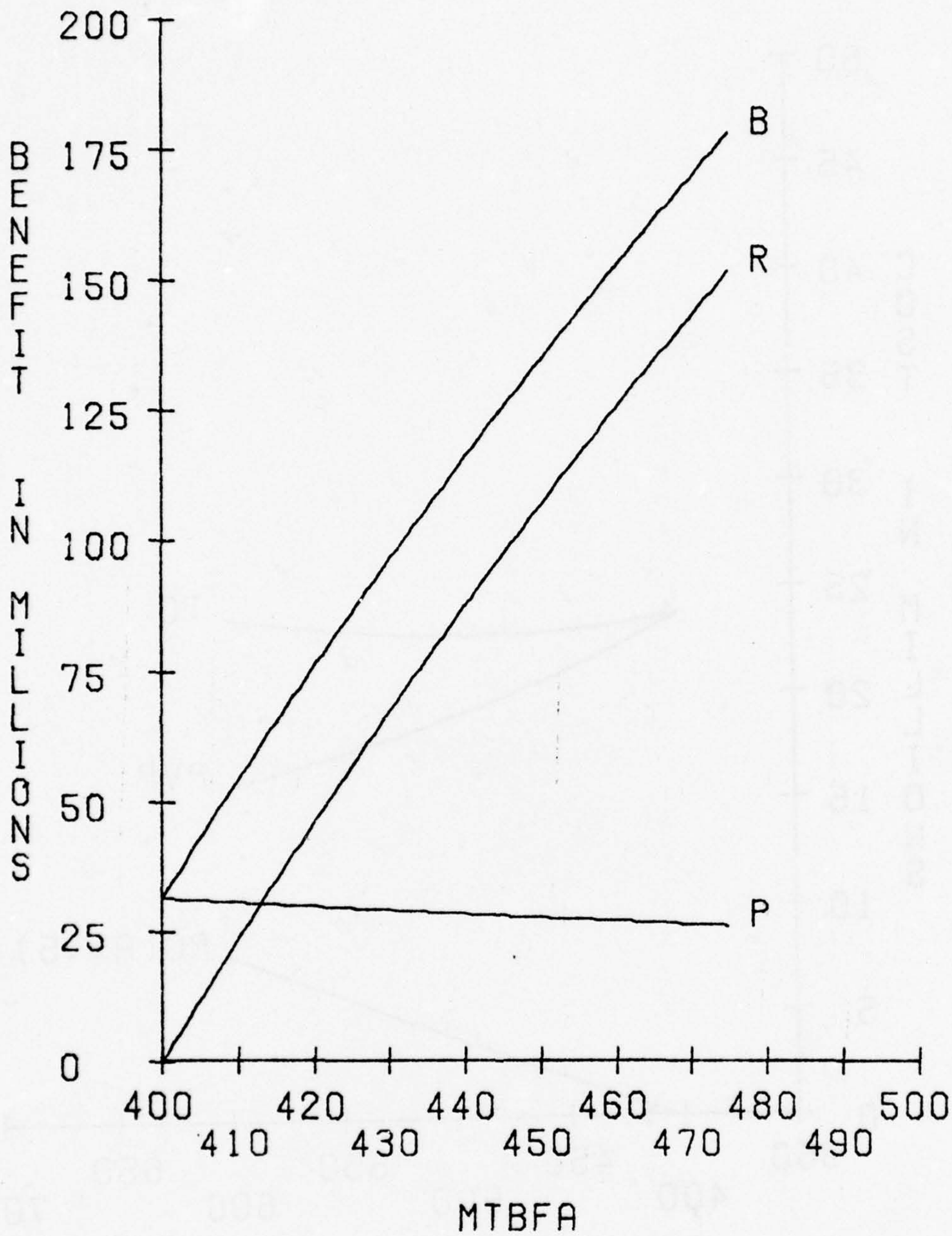


Manufacturer's Warranty Costs
(Alpha = .4)

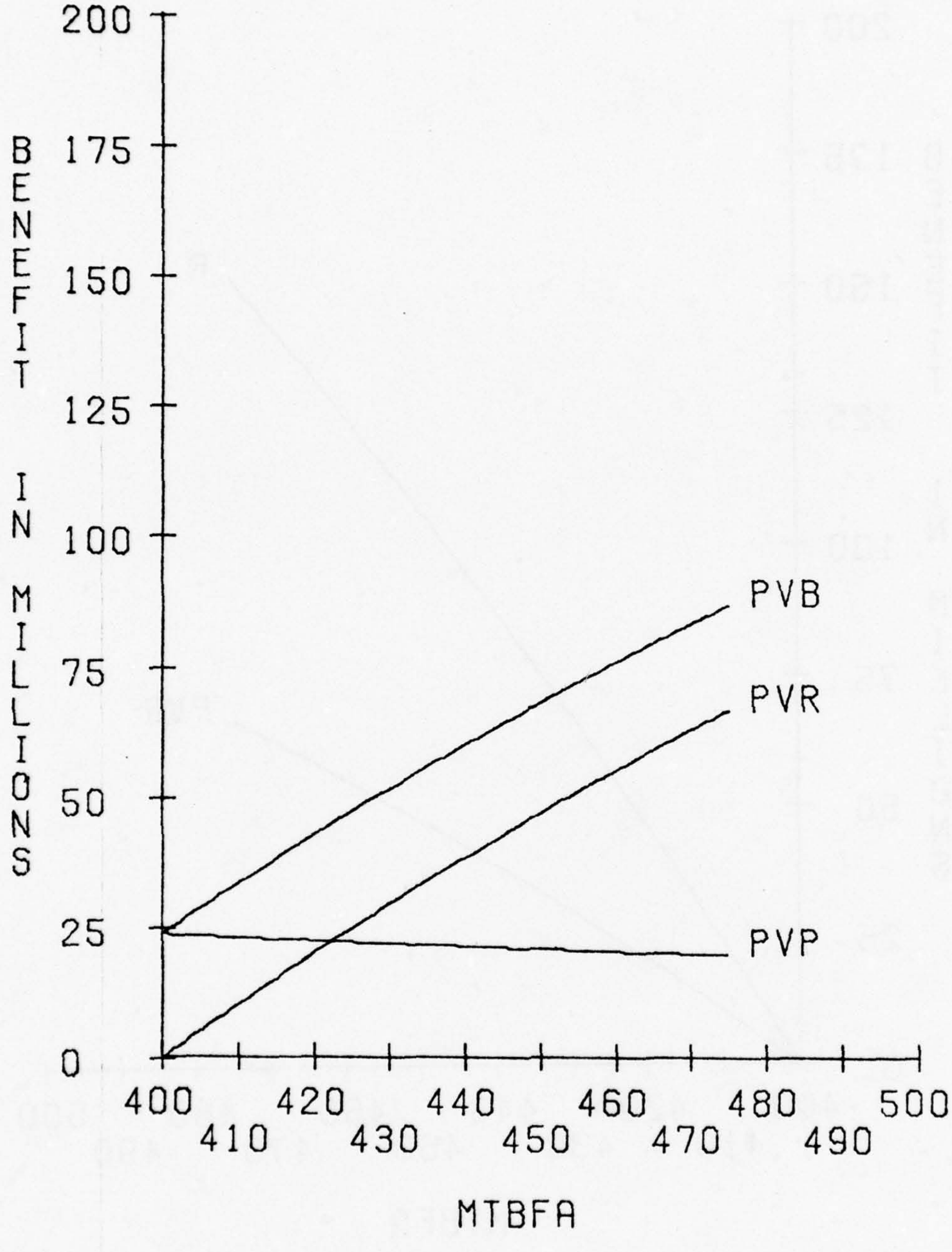


Manufacturer's Warranty Costs

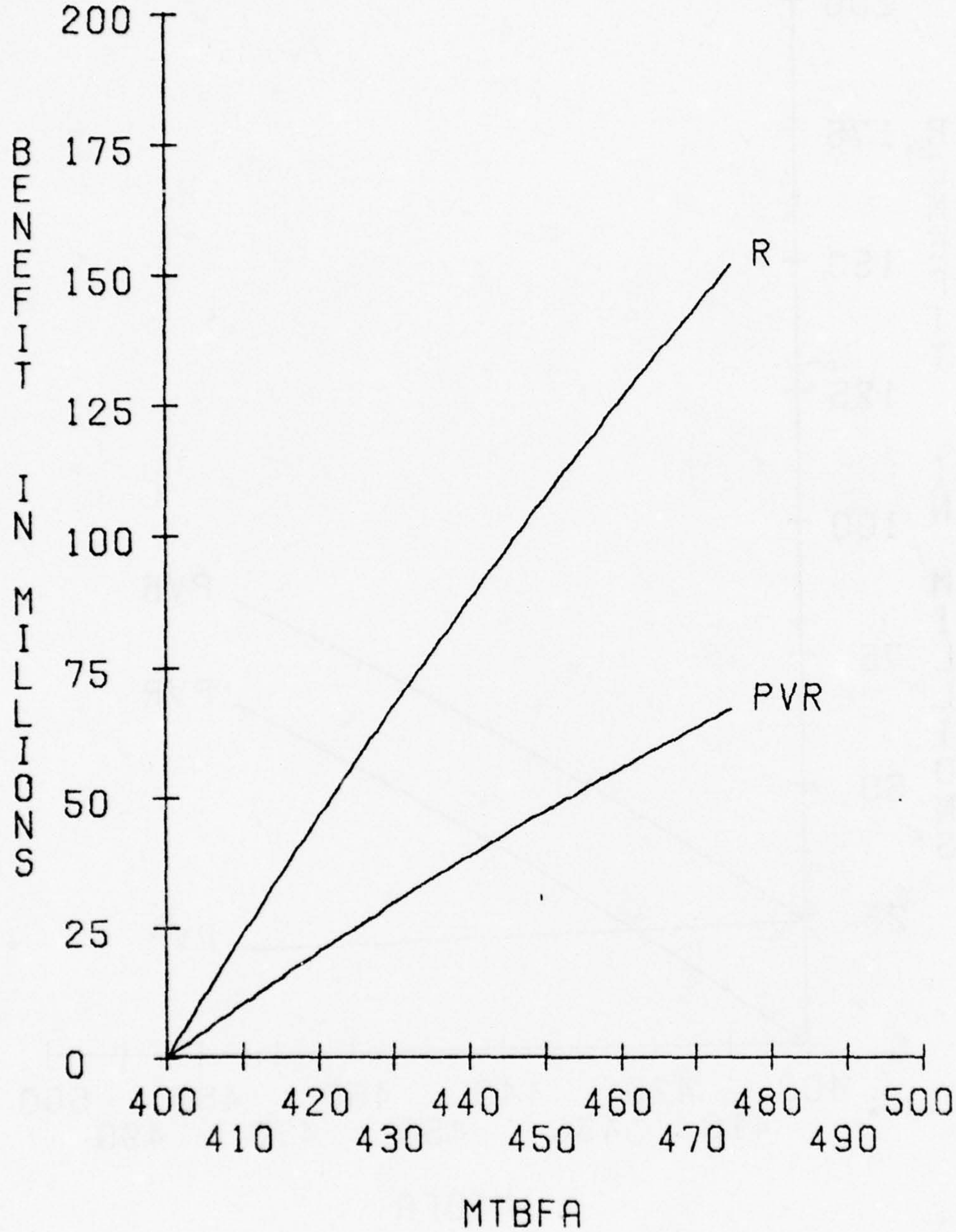
(Alpha = .5)



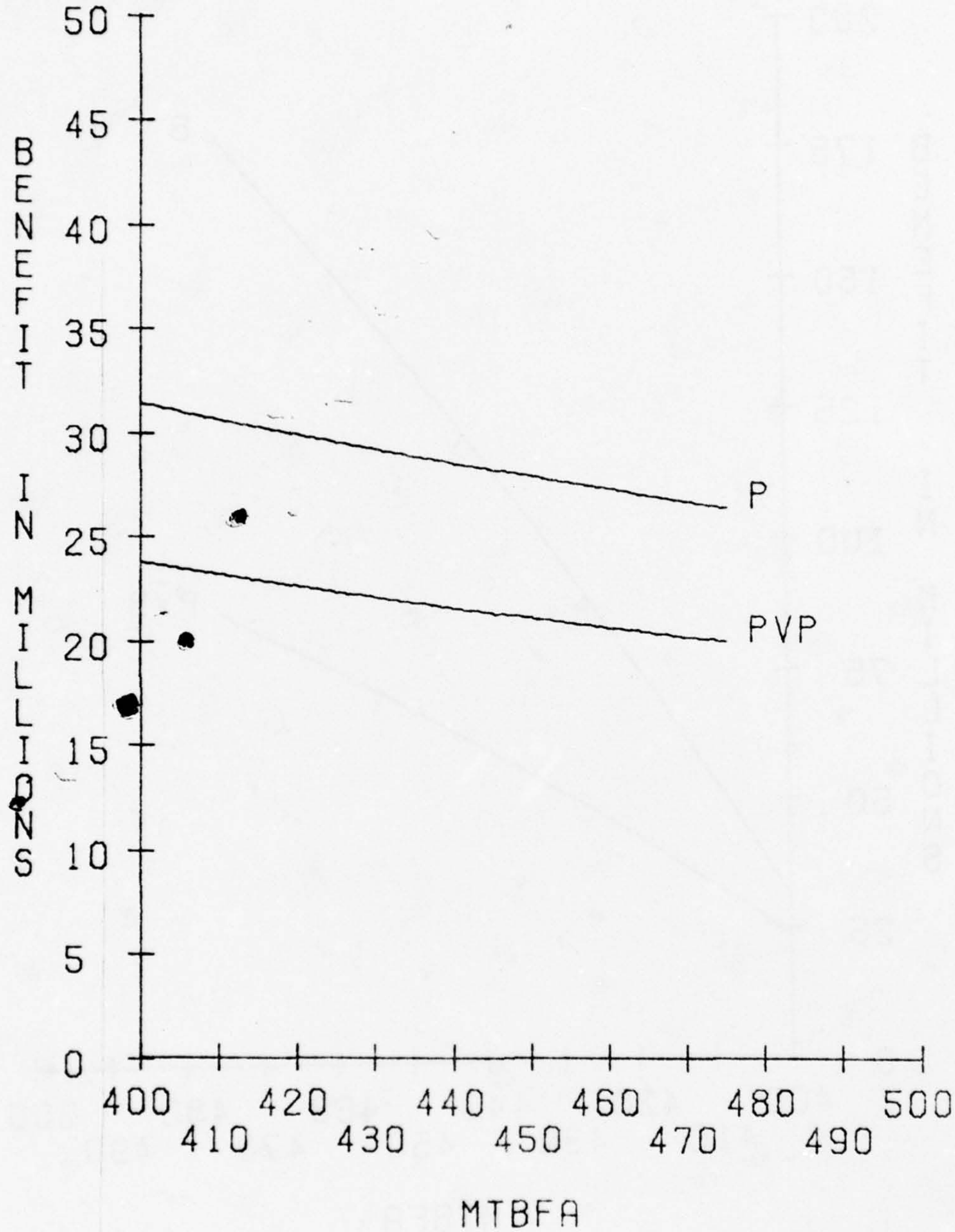
Benefit Sensitivity To $MTBF_a$



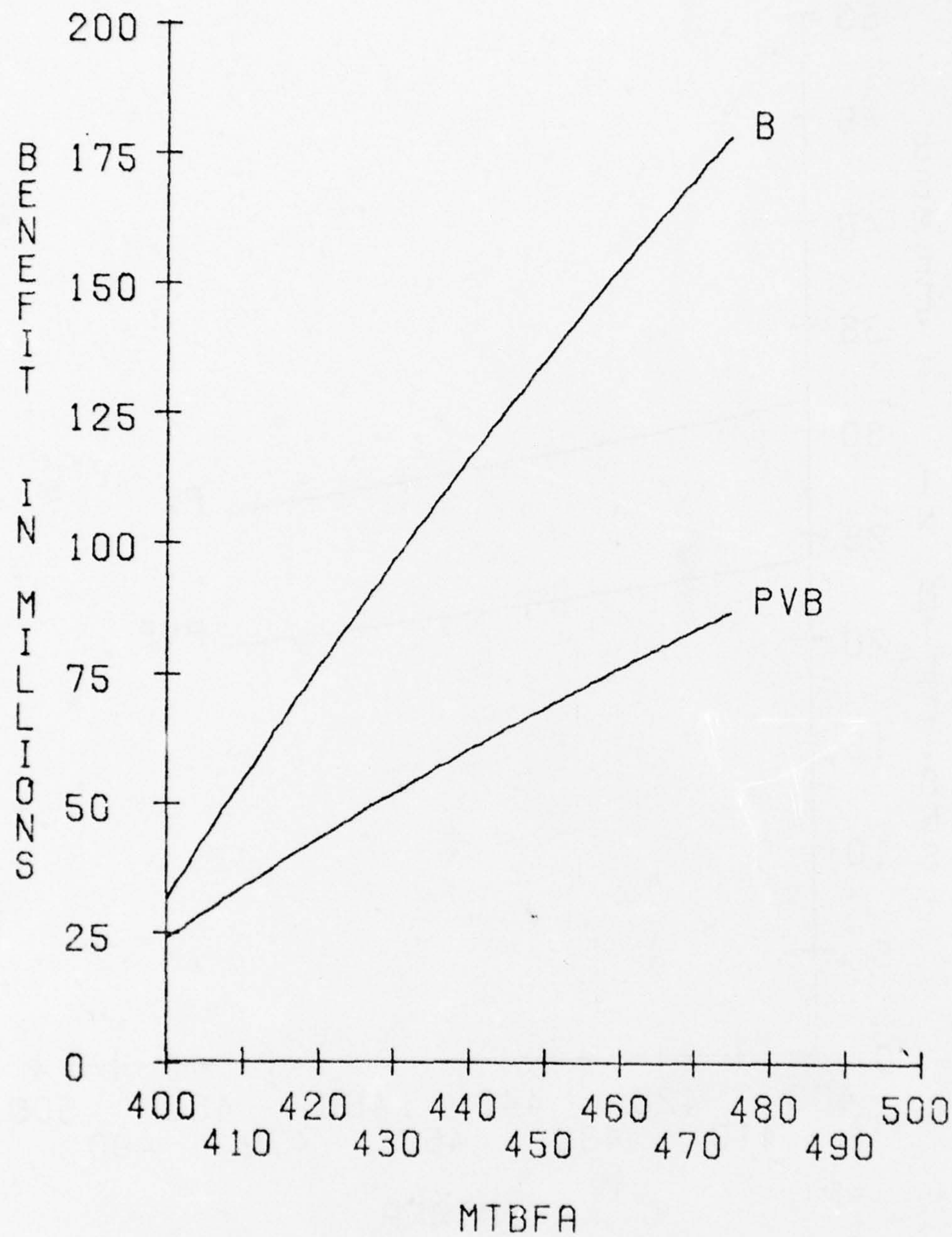
Present Value Sensitivity to $MTBF_a$



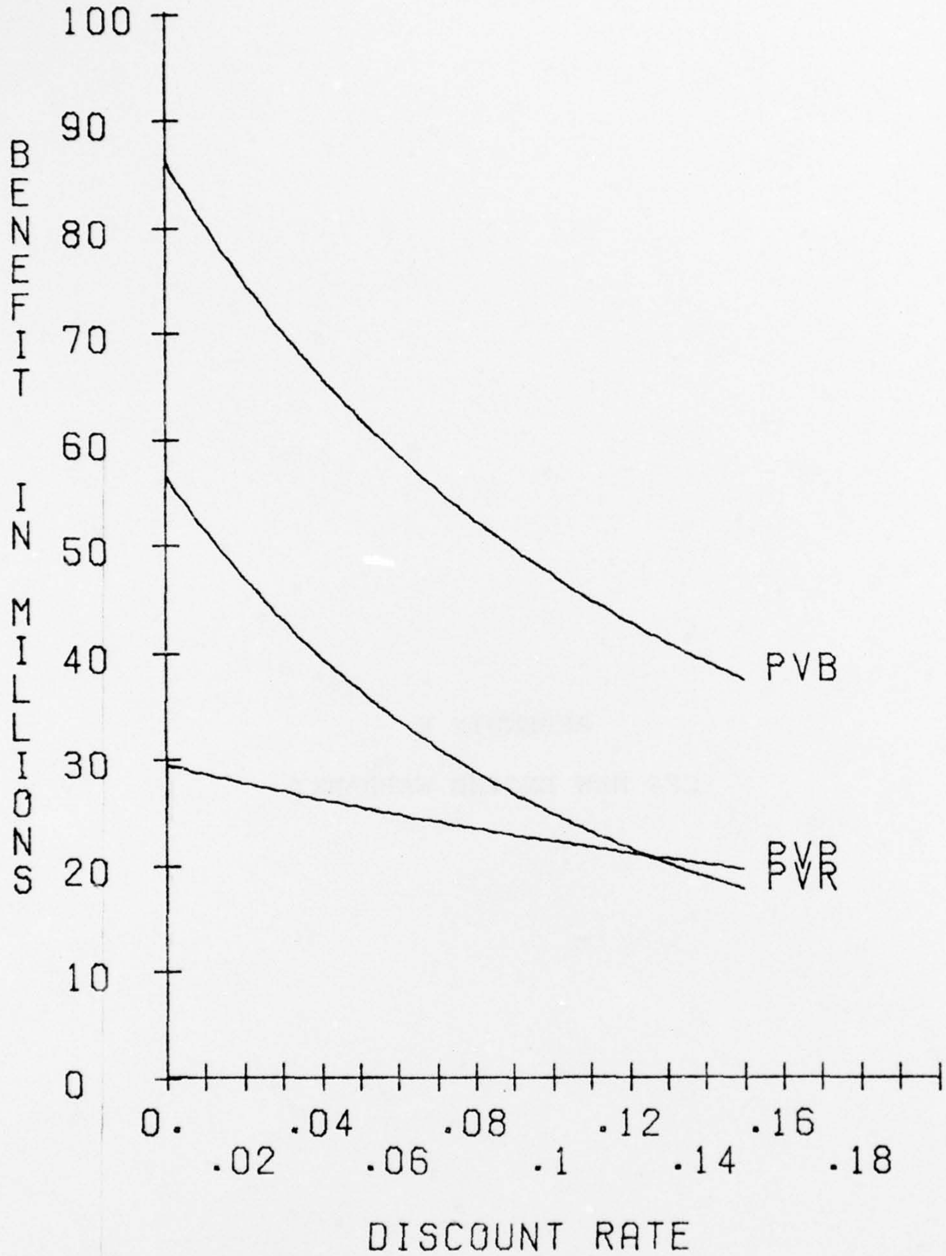
Reliability Benefit (R) Sensitivity to $MTBF_a$



Penalty Payment (P) Sensitivity to $MTBF_a$



Total Benefit (B) Sensitivity to $MTBF_a$



Present Value Sensitivity to Discount Rate

APPENDIX E

CF6 NEW ENGINE WARRANTY

SECTION 3

NEW ENGINE WARRANTY

3-1 APPLICABILITY

The New Engine Warranty covers new engines and reversers delivered to customers on new airplanes and those engines and reversers which are purchased as spares directly from General Electric by the customer. It also covers new modules which were purchased as such or new equivalent modules obtained by customer disassembly of new engines into modules.

3-2 SCOPE OF ALLOWANCES

New engines, thrust reversers, and modules are warranted against failures which are within the control of General Electric for the initial 2,500 hours of flight. In settling claims under this warranty, three categories of allowances may be used as appropriate to each claim:

a) A Parts Credit Allowance for any failed parts due to direct (primary failure) or resultant damage.

b) A General Electric Determined Labor Allowance (in hours) for disassembly and reassembly, including test if needed, when engines or modules are removed prematurely.

c) An expendable Parts Credit Allowance for those parts which are not reusable and are discarded after disassembly required to correct direct and/or resultant damage when engines or modules are removed prematurely.

These allowances will be 100% from new to 2,000 flight hours and pro rata from 100% at 2,000 hours to zero percent at 2,500 flight hours.

The warranties under this section will not apply if a replacement part is installed which at the time of its failure has more hours than those applicable herein as cited above.

3-3 ALTERNATIVE TO ALLOWANCES

As an alternative to receipt of the above allowances, a customer may request to have the failed modules, thrust reversers or engines returned to serviceable condition by General Electric. An appropriate facility to accomplish the necessary warranty work will then be designated by General Electric and transportation charges to and from this facility will be paid by the customer. There will be no

customer charge for warranty repairs for the first 2,000 flight hours. Between 2,000 and 2,500 flight hours, the customer will be charged a pro rata amount starting at zero percent of the repair cost at 2,000 hours and increasing to 100% of the repair cost at 2,500 flight hours.

3-4 ADDITIONAL MAINTENANCE WORK

Any work over and above that needed to return the engine, modules or reversers to serviceable condition as warranted will be accomplished only at the customer's request and will be billed to the customer. This includes engine overhaul, zero timing components, elective modifications, FOD, etc., which are not covered by General Electric warranties.

3-5 EXCLUSIONS

The allowances and no charge repair alternative discussed above specifically excludes costs involved in:

a) Mount and dismount of engines on the aircraft

b) QEC teardown or buildup

c) Transportation

d) Storage and packaging

e) Fair wear and tear

f) Foreign object damage

g) Vendor direct supported items

3-6 DISCOVERY OF ADDITIONAL DAMAGE

If other failed parts which were not associated with the cause for the original unscheduled removal are found during the course of New Engine Warranty repairs, these parts will be covered by the warranty except as excluded by Paragraph 3-5 above.

3-7 SCHEDULED INSPECTIONS

If engines are removed and/or disassembled for scheduled inspections or maintenance at customer's convenience (as opposed to an unscheduled removal because of an engine part failure) before 2,500

flight hours, allowances for disassembly and assembly labor and expendables will not be granted. Failed parts discovered during scheduled inspections or convenience removals before 2,500 flight hours will be covered by either New Engine or New Parts Warranties with the customer being granted the higher of the applicable parts credit allowances.

3-8 CONDITION MONITORING EQUIPMENT

Condition monitoring equipment installed on new engines is covered by the New Engine Warranty except that no labor or Expendable Parts allowance will be granted for disassembly and reassembly of any new engine, reverser or module due to inoperative, misinterpreted, or malfunctioning condition monitoring equipment.

3-9 VENDOR DIRECT SUPPORTED ITEMS

Warranties have been obtained by General Electric from the Vendors for all the direct supported controls and accessories items which include a provision that they may be passed on to CF6 users. These vendors also agreed that in any subsequent direct sales to CF6 users, warranties at least as favorable as originally negotiated with General Electric would be applicable.

Warranty claims originating from vendor part failures should be submitted directly to the applicable vendor regardless of whether the failed part was on a new engine or a spare procured directly from the vendor. (See Section 8 - Vendor Back-Up Warranty). Direct labor allowances are not granted by General Electric for vendor supported item removals and replacements. Table 1 (in the New Parts Warranty Section) Parts Credit Allowances are granted only under the Vendor Back-Up Warranty after the customer has made a reasonable effort to obtain settlement and General Electric agrees the claim is valid and General Electric has not been successful in obtaining satisfactory vendor action.

3-10 NO FIRST RUN LIMITATION

The New Engine Warranty contains no "first run limitation" or automatic cancellation on engine disassembly for scheduled maintenance before 2,500 flight hours.

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